UNITED STATES ATOMIC ENERGY COMMISSION

Twenty-second Semiannual Report

OF THE

ATOMIC ENERGY COMMISSION

July 1957

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON, D. C.

LETTER OF SUBMITTAL

WASHINGTON, D. C.,
31 July 1957.

SIRS: We have the honor to submit herewith the Twenty-second Semiannual Report of the United States Atomic Energy Commission, as required by the Atomic Energy Act of 1954.

Respectfully,

UNITED STATES ATOMIC ENERGY COMMISSION,
WILLARD F. LIBBY.
HAROLD S. VANCE.
LEWIS L. STRAUSS, *Chairman.*

The Honorable
The President of the Senate.
The Honorable
The Speaker of the House of Representatives.

Solvent extraction, as a method for selectively recovering uranium from leaching liquors, is a relatively new process in extractive metallurgy. The leaching liquors from some ores may be more economically treated by solvent extraction than by ion exchange, and it appears that this process will be of value as an alternate. The use of solvent extraction in the recovery of uranium from ores is an outgrowth of the use of solvents in feed materials plants. The original work on development of suitable solvents for use in uranium ore processing was done by Oak Ridge and by Dow Chemical. The development of processing techniques and their application have been studied by the Bureau of Mines at Salt Lake City, the Winchester Laboratory, and the Grand Junction pilot plant. As a result of this research work, three privately-owned ore processing mills have adopted solvent extraction as more efficient than previous methods.

Production of Special Nuclear Materials

During the first 6 months of 1957, production of special nuclear materials equalled or exceeded the quantity produced in the previous period and met the requirements for the military and civilian application programs. The various production facilities operated satisfactorily without major incident.

Construction of Plants

Completion date for construction of the new Weldon Spring, Mo., feed materials production center was changed from November 1957 to April 1958. As of June 30, construction was ahead of the revised schedule. The first unit, a sampling plant, was completed on February 8. The refinery began startup operations during May.

On February 4, the Allied Chemical and Dye Corp. announced selection of Metropolis, Ill., as the site of its plant to process 5,000 tons of U_3O_8 a year under contract with the Commission. The plant will produce uranium-hexafluoride feed for the nearby Paducah, Ky., gaseous diffusion plant.

Industry Participation

On April 1, proposals for the purchase of 4,000 tons of uranium-magnesium fluoride slag per year for 5 years, were received from: General Chemical Division, Allied Chemical and Dye Corp., New York, N. Y.; Hazen Metallurgical Corp., Denver, Colo.; The Spencer

Chemical Co., Kansas City, Mo.; Vitro Corp. of America, New York, N. Y.

Under the terms of the proposals, the recovered uranium will be resold to the Government.

The Commission last year announced a program to invite proposals for the construction and operation of facilities for radiochemical processing of irradiated fuel elements to be made available by the Commission. The facilities would also be capable of processing civilian power reactor fuel. In March a preliminary draft of such an invitation was sent to interested industrial firms for their consideration and comment.

The administrative and management aspects of this preliminary draft were discussed at an information meeting held in Washington on April 25. The meeting was attended by 47 representatives from 35 industrial firms and organizations. By the end of June 17 replies to the draft proposal had been received and the replies were being studied. Additional comments were expected from firms that requested more time to consider the proposal.

Pending establishment of commercial radiochemical processing facilities, the Commission announced February 18 that it had adopted a basis for providing these services to operators of private nuclear reactors (see Civilian Application).

Military Applications

During the period of this report emphasis continued on research and development activities designed to improve and increase the United States arsenal of nuclear weapons. Development programs continued on weapons employing new design principles which can be used more effectively for defensive purposes. Work went forward on methods of reducing the radioactive contamination resulting from weapon detonations.

Production continued during the reporting period in accordance with a Presidential directive on a variety of nuclear weapons, including weapons for defense against attack.

Weapons Testing

In accordance with Commission policy to use Nevada Test Site periodically for experiments or tests involving nuclear detonations of relatively low yield, the Commission on January 25 announced "Operation Plumbbob," the test series being conducted at Nevada Test Site during this year. The operation began in March and will

continue through the summer. The first test shot was fired May 28. Objectives of Operation Plumbbob include development and exploratory tests which will lead to development of weapons for defense against attack; proof tests of weapons scheduled for production; development of more efficient weapons; development of weapons with minimum fallout; and weapons effects tests in which the Department of Defense and the Federal Civil Defense Administration will participate.

Operational safety criteria for Operation Plumbbob are basically the same as those for Operation Teapot held in 1955. Each test detonation was carefully evaluated as to necessity and as to safety before it was included in the schedule. Devices to be tested were designed to have the lowest practical yield which will be sufficient for necessary research and development. Every effort was made to improve ways and means of detonating shots to reduce off-site fall-out. Improvements include: additional arrangements for forecasting of wind speed and directions; improved methods of predicting fall-out, blast intensity and location; increased height of detonation towers and use of balloons instead of towers.

Technological developments brought to the fore the possibility of using captive balloons for tests which permit some leeway in positioning the nuclear device. These balloons can be used effectively up to 2,000 feet above ground level. Several tests in the Plumbbob series will utilize this technique.

Another possible technique of reducing test fall-out would be that of firing shots deep underground so that the radioactivity would be contained. To study the feasibility of this arrangement, conventional high explosives were fired in underground tunnels at Nevada Test Site thus providing data on underground contamination and on ground shock transmitted off-site. In the Plumbbob series, an underground nuclear test is planned.

In addition to the series of nuclear tests, there will be further experiments related to assuring the safety of various weapons and experimental devices in event of accident or fire during handling or storage.

To assist general public understanding, particularly of the safety measures employed and of civil defense work, several Plumbbob tests are being opened to on-site observation by representatives of United States news media and Federal, State and local civil defense organizations, and by news and civil defense representatives from other countries of the free world which have special defense arrangements with the United States.

As in the past series at Nevada Test Site, the Nevada Test Organization was jointly staffed by the Commission, the Department of

Defense, the Federal Civil Defense Administration, and by their laboratories and contractors. Using the experience of past tests the Commission and cooperating agencies developed and refined measures to assure public safety. These are described in Appendix 10.

Weapons Facilities

Expansion of the research and development and production facilities reported in the July–December 1956 report proceeded according to schedule.

Work continued on revisions and additions to laboratory facilities at Los Alamos Scientific Laboratory, Los Alamos, N. Mex., necessitated by nuclear and thermonuclear reactor programs and the nuclear propulsion program, as well as the continuing work on research and development of weapons. The original $125 million construction program initiated in 1948 neared completion, with construction of the last major building expected to begin this summer.

Construction was completed in January on a ballistics test range located to the northwest of the Nevada Test Site in southern Nevada. It is used for determining the ballistic characteristics of inert weapons shapes dropped from aircraft.

The Atomic Energy Commission exercised an option to purchase the General Electric Co. recently completed Pinellas Peninsula Plant. The plant is located between St. Petersburg and Clearwater, Fla., and was built to produce electronic equipment for the Commission. General Electric will continue to operate the plant under a contract with the Sandia Corp.

International Activities

The growing program of international cooperation, under the President's Atoms for Peace program, was focused during the reporting period on activities pursuant to the agreements for cooperation in atomic energy development with other nations, and on activities related to the establishment of an International Atomic Energy Agency. Assistance was offered in connection with the establishment of the European Community for Atomic Energy (Euratom). Emphasis was placed on developing the program for interchange of technical information between the United States and other nations. Close liaison was maintained with the Department of State and other government agencies in these activities.

Increasingly, since the beginning of the program for international cooperation other nations have shown an interest in developing

specific atomic energy projects. Discussions have been held with 49 nations and to date negotiations have been concluded on 50 agreements for cooperation. Thirty-six of these agreements are in force, the remaining agreements await completion of statutory procedures. (See table, "Agreements for Cooperation, In Effect and Pending.")

As of June 30, two reactors manufactured in the United States were in operation in other countries, licenses to export 8 others from the United States had been issued, and 17 more were planned, including 8 power reactors.

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The nuclear reactions that are most promising for a reactor operated by controlled fusion are those involving two isotopes of hydrogen deuterium (D) and tritium (T), and helium (He). These reactions are:

(*a*) $D+D \rightarrow He^3+n+3.25$ Mev Energy
(*b*) $D+D \rightarrow T+p+4$ Mev Energy
(*c*) $T+D \rightarrow He^4+n+17.6$ Mev Energy
(*d*) $He^3+D \rightarrow He^4+p+18.3$ Mev Energy

(The symbols He^3 and He^4 stand for isotopes of helium. The symbols p and n represent the proton and the neutron.)

Reactions (*a*) and (*b*) are of great interest because they involve only deuterium, which exists in ordinary water in sufficient concentrations to permit its isolation. These two are alternative reactions that occur with roughly equal probability. Reactions (*c*) and (*d*) are of interest because of their high energy yield and also because they involve reaction between products of reactions (*a*) and (*b*). Tritium now is obtained by being manufactured in a nuclear reactor.

The energy release per fusion reaction—3.25 to 18.3 Mev—is appreciably less than the 200 Mev released in fission. However, if the energy released per unit weight (for example, per gram of material) is calculated, the energy yield per unit in the fusion process is slightly greater than in the fission process. The real interest in the fusion process arises however, from the fact that, if a fusion reaction can be achieved under control, the world will have an energy source virtually without limit. There is enough deuterium in the ocean water—about 1 part of deuterium in 6 thousand of hydrogen—to provide all of mankind's power requirements for millions of years.

The Problem of Temperature

Formidable difficulties stand in the way of developing controlled thermonuclear reactors.

The first difficulty is producing the exceedingly high temperatures (hundreds of millions of degrees) required to give the particles sufficient energy for the fusion reactions to occur.

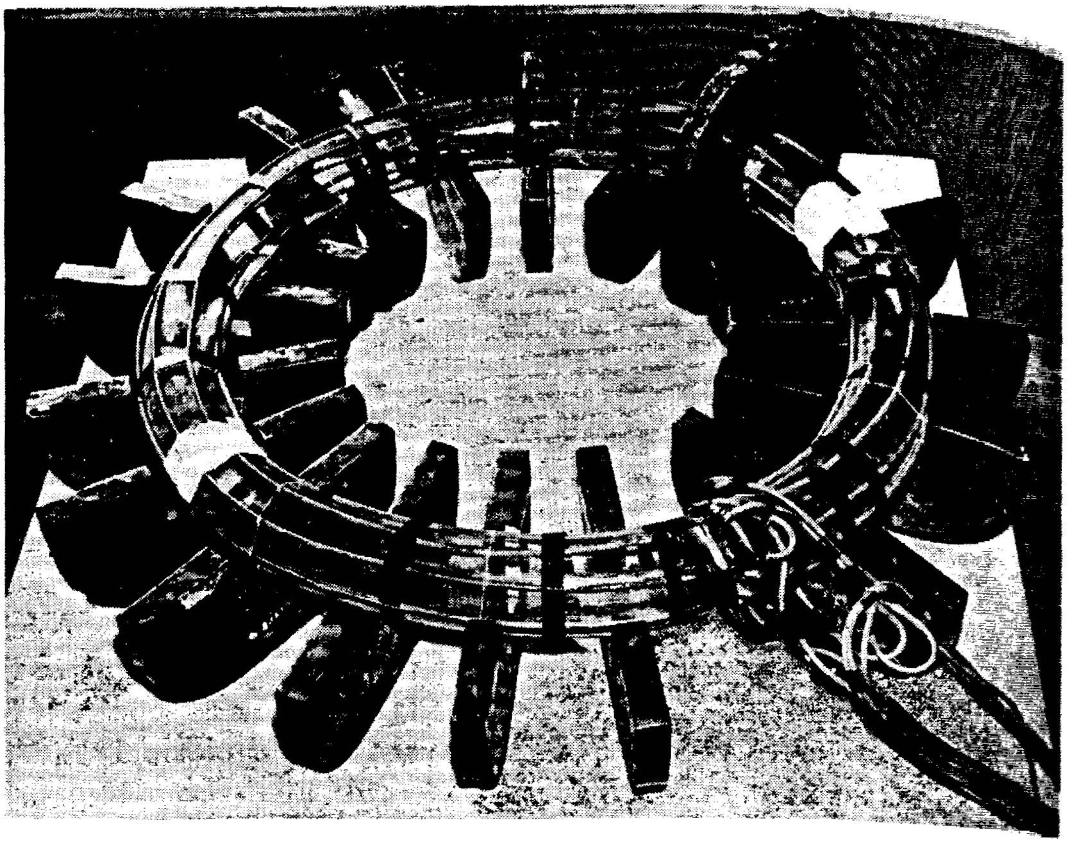
It has long been known that useful fusion power cannot be obtained by merely bombarding a target with any presently known charged particle. Even in very favorable cases, the chance of a nuclear reaction occurring before the charged particle is brought to rest is very small. However, when a hot gas is confined at temperatures of 100 million degrees or more, the probability of a nuclear reaction occurring becomes greater.

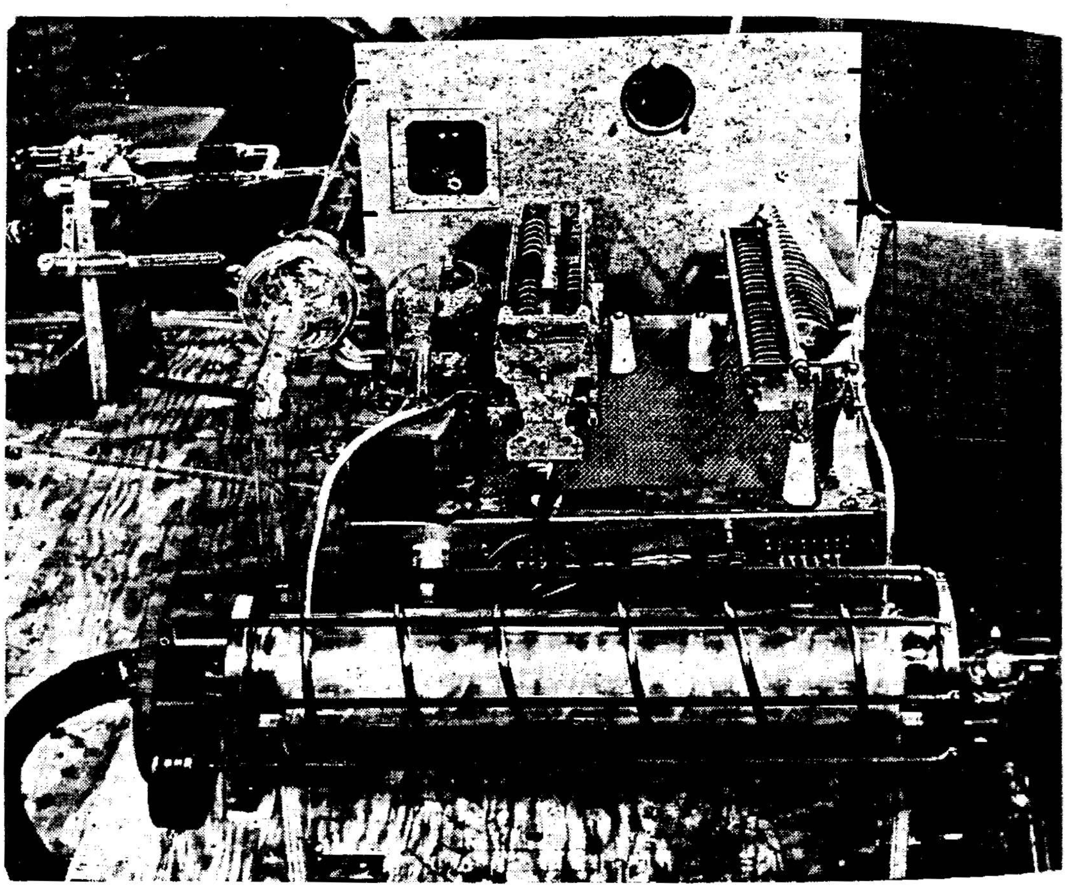
For nuclei to undergo fusion, they must be brought sufficiently close to one another so that their nuclear force fields may interact. Since the nuclei are all positively charged, they repel each other strongly. To overcome this force of repulsion they must be made to collide with one another at rather high velocities. Since the chances for the nuclei bouncing away from each other far exceed the chances of the fusion process occurring, the nuclei must be confined in some region and caused to approach one another many times, until fusion eventually does occur. This condition of having the particles in a confined region, and moving at high velocities with respect to one another, corresponds to having the deuterium at temperatures of 100 million degrees or more—temperatures, higher than those in the interior of the sun, which will vaporize all materials.

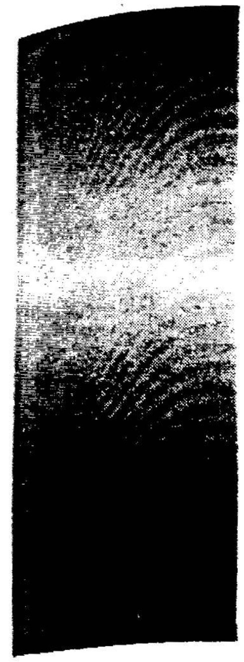
Only extremely light elements—those of low atomic number—can be considered as possible fuels in fusion reactions. Part of the reason for this is that the force of repulsion increases with the atomic number of the interacting nuclei—representing the number of positively charged protons in each nucleus. Hence the temperature required to overcome these forces of repulsion increases very appreciably with the mass number of the element used. It is for this reason that the isotopes of hydrogen are particularly interesting. Other elements with higher atomic numbers are not out of the question as possible fuels, but they would require even higher temperatures.

Another difficulty that confronts those developing a controlled thermonuclear device is making the reaction self-sustaining like a fission chain-reaction—that is, keeping the device at a temperature at which the system will remain in a steady state and not cool off.

At these extremely high temperatures, the only matter that can exist are wholly ionized gases, that is, the atoms which consist of a positive nucleus and surrounding negative electrons, are torn apart into positively-charged nuclei (or ions) and negatively charged electrons. Such a gas is called a "plasma." This plasma radiates energy at a very appreciable rate. No isolated plasma can remain at a high temperature if it gives off energy faster than it generates it. Under conditions of practical interest, when the temperature is increased, the rate of nuclear reaction rises more rapidly than the rate of radiation. Accordingly there is a minimum temperature below which the reaction cannot sustain itself by generating more internal energy than it radiates. This so-called "ignition temperature" turns out to be independent of the density of the plasma. For the deuterium-deuterium reaction this temperature is approximately 400 million degrees. For the deuterium-tritium reaction it is somewhat lower.







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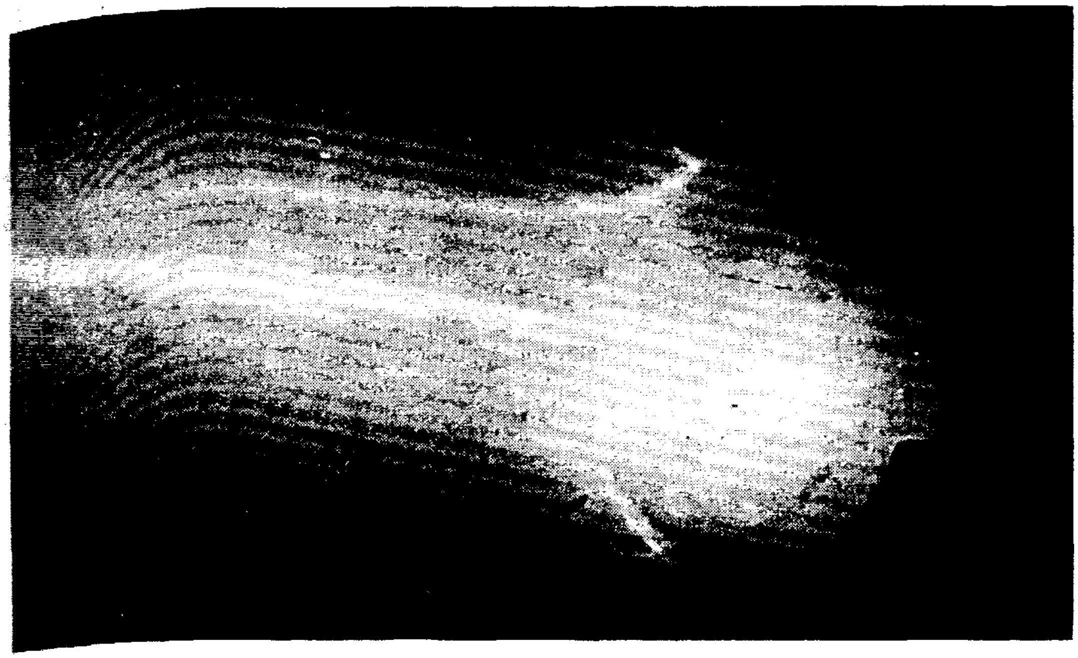


Plasma Experiments. Photograph on opposite page, taken at Commission's Los Alamos Scientific Laboratory, shows two types of equipment in which experimenters are working with ionized gases in an attempt to find methods to control a thermonuclear reaction. At top is a "Perhapsatron," a torus, or doughnut-shaped, tube in which ionized gas reactions are performed. Primary windings and iron cores of magnets used to heat the gas are shown around the tube. Below is another type of apparatus, the Columbus, a liner, rather than a circular apparatus, in which a "pinch effect" in krypton gas plasma is visible. The discharge of the gas in the glass tube (white line) shows how the plasma is "pinched" away from the walls of the tube, compressing the plasma. The Los Alamos photograph directly above shows a pinch in xenon gas in a Perhapsatron. The photograph shows the pinch of the plasma going around a curve.

Methods of Confining Plasma

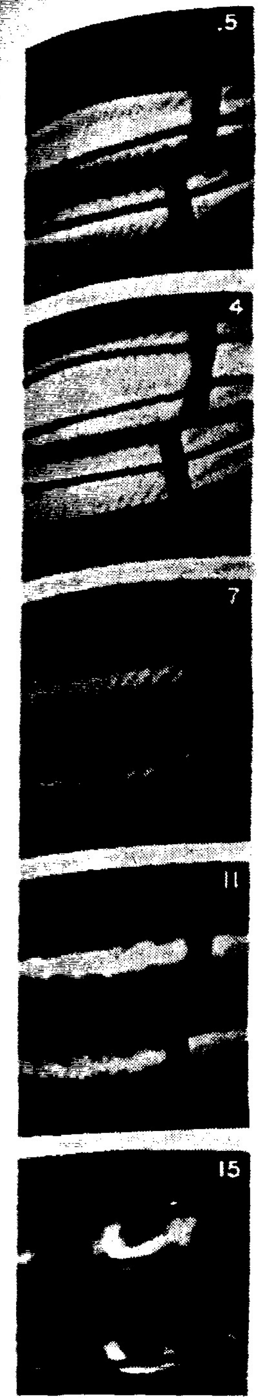
Providing adequate confinement at such temperatures for a sufficiently long period of time so that an appreciable fraction of the nuclei can undergo fusion is another problem. Clearly no materials can stand up to these enormous temperatures, hence some other means of confinement of the plasma must be found. It is known that the gravitational forces of the sun prevent the plasma from escaping from the hot region of the sun. Gravitational forces are much too weak to be useful in developing controlled thermonuclear devices on earth.

It is possible, however, to use magnetic fields to confine the plasma and to prevent it from vaporizing the walls of the reaction chamber. If a group of charged particles of the plasma are in a region in which there is no magnetic field, the particles will move in straight lines until they strike one another or until they eventually strike the walls of the reaction chamber. If a magnetic field is applied, the paths of these same particles will no longer be straight, but will be bent into tight spirals. The particles then will move down the magnetic lines of force in a path similar to the spiral stripes on a barber's pole. The only way, then, in which a charged particle can move outward toward the container walls is through colliding with other particles.

The collision shifts the instantaneous center of curvature of the particles' path. A strong magnetic field greatly reduces the diffusion of particles across the field. Roughly, they act as if they were tied to a line of force of the magnetic field. However, motions of particles along the lines of magnetic force are not impeded, and special techniques must be invoked to prevent loss of particles from the hot region in this way. One method used to prevent this loss of particles is to produce an endless discharge in a circular tube shaped like a doughnut (see photograph of Perhapsatron).

Another problem is that when magnetic force lines are employed as barriers against the escape of the plasma, pressure is built up inside the magnetic lines and the force walls imprisoning the plasma may become unstable. The force lines behave much like rubber bands around a rubber balloon, that is, they tend to bend inward and let the plasma flow out around them. At the present time, this phenomenon is one of the big difficulties, and scientists in the program are searching for an adequate solution.

The magnetic field must be strong enough to confine the ionized gas at the very high temperature required and the confinement must last long enough for nuclear reaction to take place effectively.



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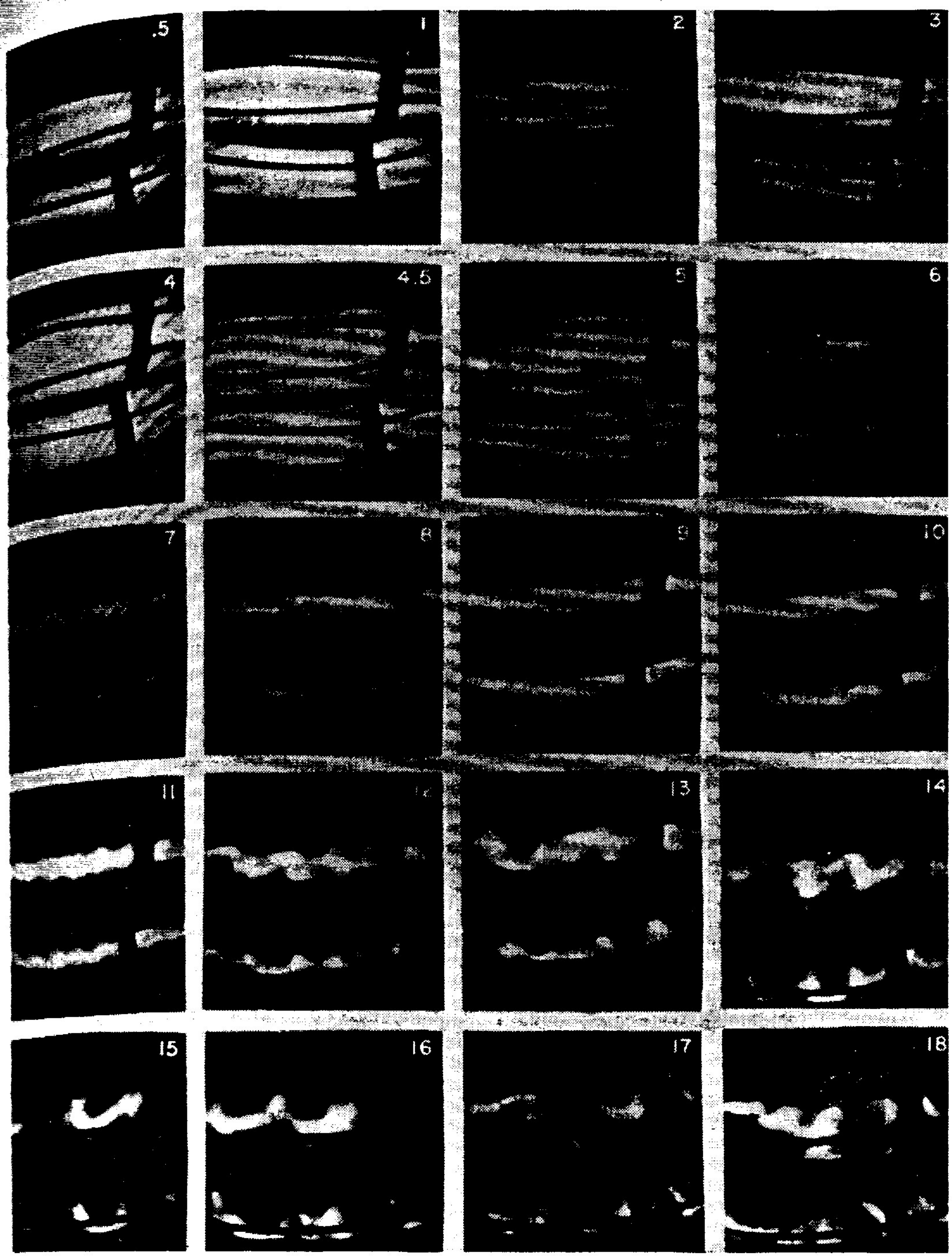

Pinch-effects. The series of photographs, taken at Los Alamos Scientific Laboratory, shows the birth and death of a "pinch" in a Perhapsatron. The horizontal black lines are primary windings and tape holding the windings in place. Two views are shown in each photograph, one from the side, the lower one in each picture being a mirror reflection from beneath. The numbers in the upper right corners of the pictures are the time, in millionths of seconds, from the start of the plasma discharge. In 6 microseconds (extreme right of second row), pinch is established. In the second row from the bottom, the pinch is beginning to become unstable.

The "Pinch Effect"

Several groups of scientists in the controlled thermonuclear program are working with what is known as the "pinch effect." They are trying to regulate the strength of the magnetic field, and to obtain a direct interplay between the magnetic energy and the energy of the plasma in order to improve stability.

The pinch effect can be described as the self-constriction of a group of charged particles moving in such a way as to produce an unidirectional current. The effect is found in another case. A heavy current, such as a bolt of lightning, can collapse a copper drain pipe when it passes through it. The effect is based upon the familiar fact that parallel circuits carrying current in the same direction attract each other.

In applying this fact to controlled thermonuclear research, the scientists are seeking, through heavy discharges of electricity, to pinch the atoms of the plasma together and suspend them in a thin line away from the wall of the container. Interesting results have been obtained in this particular effort, but much more work will have to be done. Very high temperatures have been produced in pinched discharges, but the time during which these can be maintained, at present, is in the range of microseconds. As yet, the pinch is not fully stable.

The Los Alamos Scientific Laboratory began pinch experiments in 1952 using a toroidal (doughnut) tube with and without an iron core in its early form and called it the Perhapsatron. The purpose of the Perhapsatron was to study the pinch in a toroidal geometry, with electrical equipment able to maintain currents of 10,000 to 50,000 amperes for longer times—some thousandths of seconds—than had been possible before. For short time studies of the pinch effect, a duration less than five microseconds (millionths of seconds) straight tubes are used. Such an arrangement, known as the Columbus geometry, is much simpler electromagnetically and has a higher order of symmetry than the torus. (See photograph of Columbus apparatus).

The pinch effect is but one of a number of alternate approaches being pursued in the Commission's controlled thermonuclear program. Each approach involves different configurations and different mechanisms of plasma heating and confinement.

There have been a number of interesting developments at every site of Commission-sponsored research, but all the work is still very much in the research stage. All devices built thus far have been designed for research purposes. It is anticipated that many years of intensive work will be required to develop a prototype thermonuclear

device which would yield more energy than it would consume. After that, many more years would be required to develop a full-scale device which might have a chance of competing economically with other sources of power.

CHEMISTRY

Radioisotope Facility Tested

In a demonstration of the proposed flow system of the Multicurie Fission Products Pilot Plant to be completed later this year for handling radioisotopes, which are manufactured at Oak Ridge National Laboratory, approximately 8,000 curies of cesium 137 in the form of cesium chloride powder were recovered and purified from fission product waste solutions.

New Heavy Ion Accelerator in Operation

A new linear accelerator to be used chiefly for chemical transmutation experiments went into operation at the University of California Radiation Laboratory in Berkeley on April 11. Designed especially to accelerate the nuclei or ions of very heavy atoms, the machine, called the HILAC or Heavy Ion Linear Accelerator, now is accelerating nuclei of neon 20 to energies of 200 Mev.

The machine represents, in part, a joint project between the University of California and Yale University. Berkeley and New Haven scientists jointly developed the design of the machine and a duplicate was nearing completion in New Haven, Conn. Both machines were authorized and supported by Commission funds. Though the two machines will be essentially the same, the research emphasis at the two institutions will be different. In contrast with the chemical goals of UCRL experiments, Yale will be chiefly interested in physics.

The UCRL machine may permit synthesis of elements heavier than mendelevium (element 101). Elements heavier than uranium (element 92) are all synthetic, and are obtained by transmuting uranium nuclei, step by step, into successively heavier atoms.

The UCRL instruments also will permit a new type of exploration of nuclear forces. It will open up a new field of study of the elements polonium, astatine, radon, francium, radium, actinium, and thorium. At the present time it is difficult to obtain some isotopes of these elements in pure form. The HILAC will enable scientists to bombard lead and bismuth with heavy nuclei and synthenize isotopes of elements 86 (radon) through 90 (thorium) free of heavier isotopes.

The basement, first floor, connecting wing, and patient preparatory room floor slabs were poured. All reactor and reactor enclosure foundations were completed. The installation of the reactor shielding forms, structural steel, and reactor enclosure was well under way. All phases on fabrication of the reactor components were completed and delivery to the job site was in progress.

Studies of Fall-Out

Commissioner Willard F. Libby's views on the results of studies conducted over the past four years as part of Project *Sunshine*, dealing with accumulations of radioactive fall-out from weapons tests were summarized in his address before the American Physical Society in Washington on April 26. The text of this address appears as appendix 11 to this Report.

More extensive data gathered by Project *Sunshine* were placed before the hearings of the Special Subcommittee on Radiation of the Congressional Joint Committee on Atomic Energy in May and June and will be published in the record of those hearings. Major new activities and findings of the Project during this reporting period are noted below.

Soil Sampling and Comparison of Collection Methods

The program of monitoring the distribution of fall-out over the surface of the earth by gummed paper collection was continued. It was supplemented by increased sampling of radiostrontium in soil samples taken from about 30 geographical locations outside the United States. Comparative studies were undertaken of the radioactivity retained in collection pots located adjacent to gummed paper stations in some 20 locations chosen for a variety of climatic conditions in the United States and abroad. In connection with soil samples, studies were being carried out to establish the reliability of chemical methods for estimating total strontium 90 content and the available strontium 90 content as related to available calcium content.

Distribution of Radiostrontium in Foodstuffs

A new sampling program was under way to measure accumulation of radioactive materials in flora and fauna, with special attention directed to strontium 90 in foods or assimilated by people, and the possible importance of such factors as geographic location, calcium

content of soils, and local dietary habits. Information was being collected from foreign countries on the foods which provide populations with their major sources of calcium, the average per capita consumption, and the average calcium content of each foodstuff. Samples both of foods in the composite diet and of human urine were collected by survey teams of the Interdepartmental Committee on Nutrition for National Defense, in cooperation with the Commission, for analysis here. Countries covered by survey teams were the Philippines and Turkey.

Stratospheric Sampling

Techniques were being developed to make possible the monitoring of radioactive fission products in the stratosphere. Such measurements would provide important information on quantities of weapon debris reaching the stratosphere, the distribution and retention of such materials in the stratosphere, and their release to the lower atmosphere. In experiments now being conducted with the Department of Defense, balloons are being used to carry sampling equipment to altitudes of 50,000 to 90,000 feet, where radioactive particles were filtered from a defined volume of air. Balloons are being launched at Minneapolis, Minn., San Angelo, Tex., and at France Air Force Base in the Panama Canal Zone.

Radiochemical analyses of the samples were being made on a pilot scale by the Commission's Health and Safety Laboratory, New York, until arrangements could be made with commercial laboratories to perform this work. Results of these studies will be useful in planning a world-wide network for monitoring long-lived radioisotopes in the stratosphere.

Radiation Effects

Radiation Damage to Mouse Testes

The high sensivity of the testes to ionizing radiation has been known for more than half a century. Experiments have demonstrated repeatedly that radiation depleted the spermatozoa-producing tissues of the testes and that recovery depended on the presence of some undifferentiated germ cells, the spermatogonia, which lie in the lining of the seminal tubules. However, there are divergent opinions even at the present time about the basic mechanism of the testes' dramatic response to low dosages of radiation and, on the other hand, their occasional recovery even after exposure to 1000 *r* (roentgens) or more.

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In order to explain this peculiar radiation response, it was necessary first to make a detailed study of normal spermatogenesis—the process by which mature sperm are formed. By utilizing recently developed techniques, scientists at the Oak Ridge National Laboratory identified in mice every cell in the seminiferous epithelium—the spermatozoa-producing tissues—and placed each cell in its correct position in the developmental sequence of spermatogenesis. Furthermore, an improved estimate of the time required for spermatogenesis made it possible to develop a timetable of each phase of cell development.

By relating these data to irradiated testes, experimenters clearly demonstrated that both for low and high doses of ionizing radiation, depletion of germ cells resulted primarily from destruction of spermatogonia, and not from prolonged inhibition of cell mitosis, or division. The severe initial damage to the testes and their eventual return to fertility are both readily explained by differences in sensitivity among spermatogonia. Early spermatogonial stages are most resistant: a few of these cells survive doses as high as 1500 *r* of X-rays, and in time repopulate the sperm-producing tissues. Certain late spermatogonial states are extremely sensitive, with 50 percent destroyed by 20 to 24 *r* of cobalt 60 gamma rays. A decrease in the number of these cells can be readily demonstrated after doses as low as 5 *r* of cobalt 60 gamma rays.

Early Radiation Mortality in the Chicken

Argonne National Laboratory experimenters investigated a well defined early reaction to radiation injury in chickens that generally results in death within 2 days after exposure. This reaction can be reversed by the chicken, and apparently this does not depend on the rate of exposure to radiation, or on the accumulated dose.

Investigations of the mechanisms showed that early mortality in the chicken is associated with circulatory insufficiency, manifested in chicks as a fall in blood pressure, and in the adult rooster as inadequate flow of blood to vital areas. In mammals, a vascular response to radiation has been noted soon after exposure, but it is not usually severe enough to cause death. Early radiation effects in the chicken may differ from those in the mammal in that the chain of effects leads to some event that is critical for survival in the chicken but not in the mammal. Comparisons between the radiation response in chickens which leads to early death and that which causes death after 1 or 2 weeks may yield information about the mechanisms of radiation injury.

Long-Term Effects

At the University of California Radiation Laboratory, the long-term effects of chronic irradiation in humans are being studied in relation to a series of several hundred patients who have, over a span of up to 20 years, received radioactive isotopes as therapy for leukemia, a disease of the blood cells. Although these patients have accumulated significant whole body doses, of from 25 *r* to 500 *r*, no clear-cut evidence for radiation-induced malignancy or other forms of permanent radiation damage has been observed.

Strontium Metabolism

The metabolism of strontium was studied with complete safety in 12 human beings at Argonne Cancer Research Hospital. These individuals were given strontium 85, which serves as a tracer of the fission-produced isotopes, strontium 89 and 90. Strontium 85 is a short-lived gamma-emitter in contrast with long-lived beta-emitting strontium 89 and 90.

The loss of strontium from the bodies of these subjects was found to follow about the same pattern as is the case with ingested radium. In connection with their biologic studies on strontium, the group was instrumental in developing special scintillation counting equipment that permits determination of the total-body content of strontium 85 for 1 to 2 months after oral administration of only 10 microcuries of the radioelement.

Radiation Effects on Molecules

The effects of radiation on hematin, a derivative of the iron-containing fraction of the hemoglobin of the blood cells, were studied at the University of California at Los Angeles. In dilute alkaline aqueous solutions, hematin is changed by a few thousand roentgens of gamma radiation to an oxidized compound which still has an intact porphyrin ring structure. A similar oxidized compound can be produced by adding traces of hydrogen peroxide to the solution, or by allowing the solution to stand exposed to air for several weeks.

Larger radiation doses cause rupture of the ring structure. The products formed when the ring opens are capable of reacting further to radiation, and thus partially protect the remaining unoxidized hematin. Various additives such as potassium cyanide and certain organic compounds also protect hematin.

Regulation of Levels of Circulating Blood Cells

Another investigation at Argonne National Laboratory deals with the ultimate interpretation of the hematological response to radiation injury. Consideration is given to development, distribution, and population of granulocytes, one of the types of white blood cells, under different conditions of production and utilization. To provide a background for such studies, the numbers of blood-forming myeloid and erythroid cells in bone marrow, their turnover times, and their rates of production, were estimated in various species including man.

In another study, recovery patterns were investigated in dogs after a deficiency of granulocytes in the blood had been induced abruptly either by injecting a leucocyte (white blood cell) antiserum to remove the cells by agglutination, or by exchange transfusion with leucocyte-depleted blood. Recovery appeared to be accomplished in large part by an accelerated release of young cells from bone marrow; other sources made a negligible contribution after leucopenia induced in this way. The machanisms governing neutrophil release from bone marrow also have been studied by perfusing isolated extremities of dogs with blood containing varying numbers of leucocytes.

Observations on irradiated animals indicated that the bone marrow was at first capable of releasing cells on demand, but became progressively deficient with passage of time after irradiation, presumably because the formation of new cells was blocked. In irradiated dogs, leucocyte recovery and the chances for survival appeared to increase when leucopenia was induced by the methods described above, and maintained during the first day after exposure to a median lethal dose of radiation. It was suggested that an abrupt leucopenia induced in this way might stimulate to new cell production those marrow cells still capable of responding to this physiological stimulus.

Experiments of this sort provide some understanding of the number of cells available for immediate release from bone marrow. Thus there is reason to believe that the size of this reservoir is a function of the normal state of the blood, and an idea of the nature of the control system was obtained from the various experiments.

Radiation Effects on Seeds

In a number of its laboratories and through contracts, the Commission sponsors research on the effects of radiation upon seed and plant development. Studies at Brookhaven National Laboratory were directed toward modifying the damage caused by X-rays by various treatments of the irradiated material. Experimenters found that in biological material, the effect of radiation does not stop with

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the cessation of radiation, but may increase subsequently for relatively long periods. Dormant seeds of barley were irradiated and then stored for varying periods of time; the seeds then were germinated and grown on moist blotters. Radiation damage was measured as the percent of reduction in seedling height at 7 days as compared with a normal control. It was found that, in many situations, damage was increased by as much as a factor of 3 by storage for 24 hours. There were two components in the curve of damage related to time of storage. The first component was rapid, and almost reached its maximum after approximately 24 hours at room temperature, while the second component was very slow and lasted for 5 weeks or longer.

The water and oxygen contents during and following irradiation were very important in determining the amount of damage and the magnitude of the delayed effect. Low moisture content and high oxygen tension (excess oxygen) increase the delayed effect. The temperature of the seed both before and after the irradiation was also very important. High temperatures before the irradiation protected the seed, whereas high temperatures afterward increased the damage. Pressing seeds in dry ice immediately after the irradiation retarded the appearance of delayed damage, but as soon as the seeds were warmed to room temperature the course of the damage continued. When the seeds were irradiated with fast or thermal neutrons there was virtually no delayed effect.

These experiments have many important implications as to the way in which radiation acts on cells. They indicate strongly that the action of X-ray is not by a direct hit on a sensitive target. It appears that the X-rays sensitize certain sites within the cell and oxygen subsequently completes the destruction at the site. If the site can be desensitized before oxygen can reach it, as by adding deoxygenated water, the cell will return to normal. Another possible interpretation of these experiments is that free chemical radicals are formed at the time of the irradiation in dry seeds. These can be stored for relatively long periods of time and then produce destructive effects only in the presence of oxygen.

Physics of Tissue Damage

Quantitative prediction of the radiation effects that a given radiation exposure will have on man and other living organisms is hampered by a lack of mathematical formulation of the basic ideas of the nature and extent of radiation effects. A great deal of progress in physical and engineering sciences is due to the fact that the results of experimental or operational situations can be predicted by calculations.

Recently, certain mathematical theories have been applied to the behavior of biological systems.

This application presupposes that all organisms contain in their structural components, the molecules, bits of information or "directions" which determine their further development, interruption or cessation of function and death. This development process is usually orderly as a result of a very large but finite number of bits of information in the molecular structure of the organism. A symposium was held in Gatlinburg, Tenn., under the sponsorship of Oak Ridge National Laboratory on the application of this theory, termed "information theory" to health physics and radiobiology, and was attended by leading scientists from the National Laboratories, universities and other institutions. One interesting hypothesis offered was that radiation damage is equivalent to aging which results from a loss of "information content" in the cell. The concept of "information content" can be dealt with mathematically in much the same way that "entropy" is used in the second law of thermodynamics. It may be possible to develop this concept into a mathematical theory so that it will be possible to calculate in advance the biological consequences of a planned radiation exposure schedule. Thus, radiation hazards could be treated in the same quantitative way as an engineering problem in reactor technology.

Genetics Research

Experiments have indicated that certain treatments, if applied after irradiation, may modify the amount of genetic damage caused by radiation.

Decrease in Lethal Mutations by Treatment After Irradiation

An important type of radiation damage to chromosomes is an increase in the frequency of recessive lethal mutations, a change in the germ plasm that may cause death of the offspring if the recessive change is inherited from both parents. The nuclei of all living cells contain chromosomes which are strings of chemical entities called genes that govern the heredity of the cells and consequently of the whole organism. Ionizing radiation affects genes and chromosomes, and the altered, or mutated, gene or chromosome will continue in all future generations. The recessive lethal mutation was studied at Oak Ridge National Laboratory in the one-celled animal, *Paramecium aurelia.*

Work with this organism showed that the number of lethal mutations resulting from a dose of radiation could be decreased after irradiation by starvation, or exposure to streptomycin or 2,4 dinitrophenol, which slow the growth and division of the cell. To be successful, treatment must be started within an hour after irradiation. The experiments showed that, for an appreciable time after irradiation, at least part of the mutation process is not irrevocable, and that during this time, the radiation damage that leads to mutation can be reversed. A possible interpretation of the mechanism of the successful treatments is that they delay the irrevocable formation of the mutations, and thus allow more time for recovery from the initial radiation damage.

Reduction in the amount of mutation was found following irradiation with alpha-particles as well as with X-rays. Previously, other procedures that modified X-ray damage failed to give protection against damage from heavy particles such as alpha-radiation.

Post-Irradiation Modification of Chromosome Aberrations

One form of radiation-induced genetic damage that has lent itself readily to quantitative studies is chromosome aberration. When ionizing radiation breaks chromosomes, the fragments may remain separate or rejoin. If they remain separate the cell usually dies because the piece broken off and its necessary genes are ultimately lost. If the breaks rejoin, they may reform the original chromosome—which would not be detectable as an aberration—or may join with another fragment different from its original part. The latter combination, known as a chromosome exchange, is in many cases also lethal to the cell. Since almost all genetic changes brought about by radiation are deleterious, fundamental studies were carried out on breakage and rejoining of chromosomes in the hope that, after better delineating these two processes, scientists could devise methods of modifying the amount of genetic damage.

Work performed at Oak Ridge National Laboratory, partially characterized the chemical nature of the induced breaks and indicated that certain post-irradiation treatments can modify the number of aberrations induced. In the seed of *Vicia faba* chromosome segments remained separated for as much as 2 hours; rejoining depended upon cellular metabolism and the production of adenosinetriphosphate (ATP). ATP is a high-energy phosphate compound utilized as a source of energy in the living organism to drive most anabolic reactions. Since the chromosome breaks stay open for long periods of time, and also require a source of energy for their closing, it was postulated that the breaks involved are breaks of covalent chemical bonds in which

two atoms are linked by sharing the same electron or electrons. Another type of break which closes very rapidly also is induced. This break might involve a different type of chemical bond.

By inhibiting the metabolic processes of cells after irradiation it was possible to decrease the amount of ATP available. This prevented rejoining and kept chromosome segments separate. If the chromosome breaks are kept open until additional breaks are produced by more radiation at a later time, the earlier breaks then can rejoin with the later ones and yield an increased number of exchange linkages. The converse experiment, in which ATP was added, caused breaks to close faster, and thus segments from a first dose of radiation were not capable of rejoining those caused by a second dose. Less damage then resulted.

Protection Against Radiation

Long-term Protection of Irradiated Mice

When AET (2-aminoethylisothiouronium.Br.HBr) administered to mice before irradiation was combined with bone marrow injections after irradiation, the mice were found to tolerate 2 to 3 times the amount of radiation which would have killed 50 percent of the untreated control animals in 30 days.[33] The survivors of these high levels of radiation—1,400 to 2,600 *r* of whole body X-ray or gamma radiation—were observed at Oak Ridge National Laboratory throughout their lives, for periods up to and exceeding 2 years after irradiation, to determine the extent to which the protective agents would prevent delayed effects of radiation.

Preliminary data indicate that, in general, protection was afforded against the life-shortening action of radiation that was similar to the protection given against death within 30 days. Since most animals observed to date received both AET and bone marrow, comparisons between benefits from the two agents must await the results of current experiments.

The protection observed in these experiments confirmed the results of earlier studies with spleen-shielding, reducing the oxygen tension or administering cysteine, and demonstrated that protective and recovery-promoting measures are effective not only against acute effects of irradiation, but also have an effect on delayed injury.

[33] See p. 85, Eighteenth Semiannual Report (January–June 1955).

Mechanism of Delayed Reaction to Foreign Bone Marrow

Many mice protected against acute irradiation death by injection of a foreign bone marrow, such as from a normal rat or a normal mouse of a different strain, subsequently died of a delayed reaction. The serum proteins in the treated animals' blood was identified as its own, not that of the donor; electrophoretic analysis of these serum proteins showed increased gamma globulin and decreased albumin concentrations during this delayed reaction. Immune response studies revealed that treated mice were capable of responding to sheep antigen but not to mouse or rat antigens. From these findings, it was deduced that the delayed foreign bone marrow syndrome was due to an antigen-antibody reaction of the host's immune mechanism against transplanted, proliferating foreign tissue.

Recognition Factor of Antibody-producing Cell

The ability of irradiated mice to produce antibodies to cells of another species injected into their bodies was tested using as antigens the red cells of the rat, a closely related animal, and of the sheep which is more distantly related. It was found that although normal mice produce antibodies to these two antigens equally well, irradiated mice responded to sheep antigen more strongly than to rat antigen. This was interpreted to mean that irradiated mice's systems were able to recognize foreign antigens in proportion to the degree that its species was remote from the recipient.

This ability of the immune mechanism to recognize and react variably helps explain why the transplantation of bone marrow between closely related species (mouse to mouse, or rat to mouse) is more successful than between distantly related species (rabbit, dog and monkey to mouse). Some preliminary irradiation of the host seems to produce a sort of paralysis of the immunity mechanism. The antibody reaction against foreign cells is depressed still further with the result that the frequency of successful transplants is still greater in the irradiated mice. Unfortunately, the host must be heavily irradiated to accomplish the necessary depression of the immune mechanisms.

The recovery of the immune antibody-antigen mechanism of mice pre-treated with MEG (2-mercaptoethylguanidine hydrobromide) and then exposed to 950 r was shown to be comparable with that of mice exposed to 950 r and then post-treated with bone marrow from the same strain of mice. It was deduced that there existed either different types of antibody-producing cells, or an antibody-producing cell with the ability to recognize varying degrees of antigenicity, i. e., (a) homologous (antigen from another strain of the same species) (b)

closely related heterologous (rat, guinea pig in relation to mouse), and (c) distantly related heterologous antigens (man, rabbit, and sheep in relation to mouse). In terms of these hypothetical properties, the degree of destruction of antibody-producing cells by X-rays would be in the order mentioned. This hypothesis was experimentally substantiated in part. Mice treated with MEG and exposed to 9[illegible] r accepted transplants of homologous bone marrow but would not tolerate transplants of closely related heterologous bone marrow.

Mechanism of Red Blood Cell Production

The mechanism of the action of erythropoietin, a hormone that controls the production of red blood cells, was traced at Argonne Cancer Research Hospital. Researchers established that it is the relationship of the oxygen supply in the tissue to the tissue demand for oxygen, rather than either of these factors acting independently, that controlled red blood-cell production through the action of the hormone. Cell production was profoundly decreased in rats in which the tissue supply of oxygen remained normal while demand was reduced by acute starvation or removal of the pituitary gland, and also decreased in rats in which the supply of oxygen was increased by transfusion-induced oversupply of red cells or hyperventilation but the demand remained normal. Rats so treated responded in an exaggerated manner to injection of a plasma rich in erythropoietin.

Red blood-cell production increased in rats in which the demand for oxygen was increased by injecting the chemical compounds, dinitrophenol or triiodothyronine while the supply remained normal, and in rats in which the oxygen supply was decreased by repeated hemorrhage or induced anemia while the demand remained normal. Evidence now points to the kidney as the site of production of erythropoietin, although it is possible that the hormone may be formed elsewhere as a precursor activated by the kidney.

Extension of this investigation to human beings revealed that erythropoietin was present in very small amounts in the plasma of normal healthy male subjects.[34] However, its concentration was markedly elevated in two-thirds of the anemic patients studied. The hormone appeared in the urine of some anemic patients but not in the urine from normal persons. The feasibility of using erythropoietin in clinical trials was considered since it might prove valuable in anemias resulting from chronic infection, chronic systemic diseases, and kidney diseases, as well as for supportive treatment in radiation sickness.

[34] See p. 83, Twenty-first Semiannual Report (July–December 1956).

The role of the pituitary also was investigated in relation to its action in hemoglobin formation. Animals whose red blood cell production has been inhibited incorporate very little iron into hemoglobin. This incorporation, however, can be greatly increased by minute amounts of pituitary material or by a fraction isolated from circulating plasma. The chemical isolation of the pituitary principle and its relation to the plasma erythropoietic hormone in both animals and man has been under investigation at the University of California Radiation Laboratory.

Toxicity Studies

Tests for Uranium Body Burdens

A problem of long-standing importance in maintaining safe working conditions in uranium-processing plants is that of defining the quantitative relationship between uranium excretion from the body—measured routinely among uranium processors—and its long-term storage in tissues and organs.

Investigations started several years ago at Oak Ridge National Laboratory determined the pattern of excretion of uranium and its deposition in organs and tissues for man so that it was possible to estimate the burden of uranium in the body within a factor of three from the measured urinary excretion. Attempts will be made to secure a more precise estimate.

Through studies with dogs, it was found that:

- Ingested or inhaled uranium is eliminated predominantly via the gastro-intestinal tract.
- About 10 percent of an inhaled dose of uranium is absorbed into the blood stream, whereas only about one-tenth of one percent of ingested uranium is absorbed.
- The levels of uranium in the feces decrease as much as 500-fold within one week after ingestion; but in the case of inhalation, the decrease is more gradual and shows a 20-fold reduction in one week.
- Urinary excretion levels follow a course similar to the levels in feces; at most a 20-fold reduction is evidenced when uranium is inhaled, while a reduction of the order of 100-fold occurs when the uranium is ingested.

In studies with mice, a pathological effect on the gastro-intestinal tract was not found after 120 days of continuous oral administration of uranium 233 in the drinking water at about 100 times the maximum permissible concentration. These studies are being continued.

Uranium mines. In cooperation with the Public Health Service and the Veterans Administration (Veterans Administration Hospital, Grand Junction, Colo.) investigations were being conducted by the University of Rochester to define better any hazard in uranium mines that may exist due to the radioactive gas, radon, that occurs in association with uranium.[35]

Dogs exposed for 110 days in one mine will be returned to Rochester for long-term measurement of radioactivity in the urine, and eventually of total body stores of radioactivity. Dogs and other animals were exposed to experimentally produced radon atmospheres at Rochester. From these measurements, and from studies on uranium miners themselves, it is expected that occasional measurement of urinary samples will make it possible to warn if cumulative exposure approaches a potential danger line. This may reduce the need for day-by-day monitoring of all working areas in the uranium mines themselves.

In other experiments, animals inhaling atmospheres containing large amounts of radon, specifically half the lethal dose, showed no definable decrease in life-span. In studies on mice highly susceptible to lung cancers, the incidence of lung cancer was not increased following radon exposures.

Beneficial Applications of Atomic Energy

Thyroid-Uptake Calibration and Seminar Program

Three years ago the Oak Ridge Institute of Nuclear Studies undertook a program to "standardize" the iodine 131 thyroid-uptake techniques so that results would be comparable regardless of the particular type of apparatus employed in the different laboratories. Life-size half-body mannequins containing simulated thyroid glands with suitable amounts of "mock-iodine" giving off a gamma-emission spectrum closely approximating that of iodine 131 were sent for testing to some 300 scientists in the United States and England. Using these test results, and data from basic studies at ORINS, a seminar in September 1956 helped establish methods for inter-laboratory calibration and during the last 6 months five additional seminars were held on methods likely to give the most reliable results. Two seminars, January 14–15 and February 11–12, were primarily for invited groups of physicians and physicists; two, March 18–19 and April 15–16, were open to all qualified physicians and physicists; and one was held May 17 for representatives of manufacturers of uptake-calibration equipment. One will be scheduled later for qualified technicians.

[35] See pp 223–225, Twenty-first Semiannual Report (July–December 1956).

Tracer Studies

Hormone research. Control of carbohydrate metabolism by means of hormones was studied at Brookhaven National Laboratory in a collaborative research project with the New York University Medical School. Glucose labeled with radioactive carbon 14 was used to study the pattern of glucose uptake and production after insulin injection.

A small dose of insulin was administered intravenously to experimental animals in the post-absorptive state, that is, several hours after a meal. The resulting decrease of the blood sugar level was traced almost exclusively to an increase in the rate at which tissues took up glucose from the blood. There was also a transient, early, minor decrease in the rate at which the liver contributed glucose to the blood stream. The maximum uptake of glucose by the tissues occurred 10 to 15 minutes after insulin was injected; subsequently, the rate of uptake fell off sharply, but it did not drop below the pre-insulin level.

The blood glucose concentration then returned to its previous, normal level as a result of an abrupt increase in the liver's output of glucose. This increased rate of output first appeared about 15 to 20 minutes after insulin was given, and just after the period of maximum uptake of glucose by the tissues. The output rate reached its maximum 20 to 30 minutes after insulin injection. As the blood glucose concentration approached normal, the rate of glucose production by the liver returned nearly to the pre-insulin level.

A regimen of growth hormone injections was found to restore to normal the impaired ability of the liver to put glucose into the blood of a hypophysectomized dog—one with its pituitary gland removed. This was observed both in the resting post-absorptive state, in which the blood glucose turnover rate is raised to normal, and also in response to the extra demand for glucose brought about by insulin-induced shortage of blood sugar. A regimen of cortisone injections was found to produce the same effects as the growth hormones in the hypophysectomized dog.

The liver of the adrenalectomized dog—one with its adrenal glands removed—was found to be considerably less deficient in glucose-producing ability. This is understandable, since the dog's intact pituitary gland was secreting a growth hormone which partially compensates for the missing adrenal cortex secretion. The hypophysectomized dog lacked growth hormone and also lacked a sufficient secretion of the cortisone-like adrenal hormones, since the ACTH secretion from the pituitary was not present to stimulate adrenal

secretion. Thus, the hypophysectomized dog's liver is most inadequate in glucose output, but it can be restored to normal either by growth hormone or cortisone.

The action of growth hormone or cortisone in bringing about a diabetic state when administered in large amounts is ascribed to the resulting overproduction of glucose from the liver. At first, the pancreas responds to the extra glucose by secreting extra insulin. This was shown in experiments by the finding that glucose uptake by the tissues is increased in the whole animal early in a regimen of growth hormone administration, in spite of the fact that growth hormone inhibits uptake of glucose by the tissues. When the pancreas no longer can secrete enough insulin to handle the over-production of glucose, the diabetic state is produced.

Radioactive manganese in liver tumors. The goal of a series of studies at Brookhaven National Laboratory is to place an element or a compound upon a specific physiological target, so as to permit effective therapy with a radioactive isotope and safe diagnostic procedures with radioactive isotopes. Besides these objectives, the studies open the possibility of other research on specific target distribution of drugs already in use. Success in such studies could reduce the hazard of many drugs now employed and at the same time increase their effectiveness.

One series of studies was carried out with the beta-gamma emitter manganese 56.[36] It was observed that, following intravenous injection into test animals, by far the largest fraction of the isotope could be found in the liver within 3 minutes, and it persisted there at least 30 minutes after injection. It was observed also that the radioactive isotope was removed very rapidly from the blood, and no significant fraction accumulated in bone marrow.

Subsequent observations suggested that the biological half-time in the liver was about 4 hours. Since the radiological half-life of manganese 56 is 2.6 hours, about two-thirds of the radiation which the isotope could deliver would be emitted during the time it was in hepatic structures.

Therefore, this isotope was considered as promising for possible therapy in hepatoma (tumor of the liver), since the hazard to the blood appeared small and the strong emission of short-range beta particles would provide effective local radiation. Cautious trial of manganese 56, in cancer of the liver which had been metastasized (transported elsewhere in the body) indicated that it did have a palliative effect, but that the depressive effects of radiation on the blood-cell producing system were significant and much greater than ex-

[36] See p. 102, Twentieth Semiannual Report (January–June 1956).

APPENDIX 11

REMARKS PREPARED BY DR. WILLARD F. LIBBY, COMMISSIONER, FOR DELIVERY BEFORE THE AMERICAN PHYSICAL SOCIETY, WASHINGTON, D. C., APRIL 26.

RADIOACTIVE FALL-OUT

I. Introduction

The radioactivity produced by the fission reaction changes its characteristics continuously and rapidly following the explosion of an atomic weapon and the conditions of firing are of extreme importance in determining the rate of which the radioactivity descends to earth. As a result there are in general three different kinds of radioactive fall-out, the relative importance of which is determined by the nature of the weapon, principally its yield, and the conditions of firing. These three types are: First, *the local fall-out*, which is insignificant unless the fireball touches or comes close to the ground, but which in case the fireball does touch the ground, can amount to a major fraction, in some instances as much as [illegible] percent of the total debris. This type of fall-out consists of radioactivity which is carried down by the larger particles. It consists largely of matter drawn up into the fireball from the surface which is either totally or partially vaporized. Under these conditions so much matter is vaporized by virtue of the fireball's touching the ground that the particle sizes formed in the freshly cooled vapor are large.

The second and third types of radioactive fall-out are world-wide in nature and consist of finer material and are divided according to whether the material happens to lie in the lower part of the atmosphere, the troposphere, where rain and weather phenomena occur, or the higher part of the atmosphere, the stratosphere, which is free of such precipitating mechanisms. The *tropsopheric fall-out* occurs in a matter of two or three weeks or a month or so. It occurs largely as a result of rain and snow, and water precipitation in general, and falls in the general latitude of the test site. The *stratospheric fall-out*, in contrast, takes years. We are not completely certain, but it appears that an average time of something like 10 years, or perhaps somewhat less, is a reasonable figure, and during this time the distribution becomes nearly worldwide. When the stratospheric fall-out manages finally to pass into the troposphere it is quickly removed by the same type of mechanism that brings down the worldwide tropospheric fall-out, namely rain and moisture. The precipitating mechanisms consist in general of the collision of the tiny particles with moisture droplets in clouds, together with the interception of particles by falling raindrops. The first mechanism was recently suggested by Dr. Greenfield in connection with Sunshine problems—the study of worldwide fall-out is called Project Sunshine. In addition to the scavenging action of rains and fogs, there is definite evidence for a considerable probability of pick-up by direct contact of air with surfaces such as the leaves of grass and trees. Frequently, grasses are found to have higher strontium 90 content than would correspond to the soils in which they grow, and this is due undoubtedly to direct pick-up.

The dissemination of strontium 90 and all fall-out is greatly dependent upon the firing conditions. There is every evidence that important factors include not only

contact of the fireball with the surface, but the nature of the surface, whether it be land or water and the type of soil and the composition of the water, whether fresh or sea water. Also, the height to which the fireball rises is important, in particular the height relative to the tropopause, the dividing layer between the troposphere and the stratosphere. Yield is the main consideration here. A rough rule is that megaton weapons push through the tropopause into the stratosphere, and kiloton weapons stay below the tropopause in the troposphere.

Thus, we see immediately that kiloton weapons deposit their fission products much more quickly than do megaton weapons. Of course this is of less importance in so far as the long-lived fission products, such as strontium 90 and cesium 137, are concerned, but it is of more importance for the shorter-lived fission products. As a general rule, an air-fired kiloton weapon will deposit its radioactive fall-out in a period of between 2 weeks and 1 month on the average after the detonation, whereas an air-fired megaton weapon will deposit its radioactive fall-out over many years—on the average about 10 years. Thus, the effects which are due to the short-lived fission products are larger for a given amount of fission energy release in kiloton weapons than they are for air-fired megaton weapons. Considering the average age of the kiloton fission products to be 1 month, the external gamma ray exposure from one megaton of fission fired as say 50 bombs of 20 kilotons each would be 30 times that for a single bomb giving one megaton of fission energy—if both were fired well up in the air. The fission products from the small bombs fired in Nevada would fall in the latitudes 10°N. to 60°N. in about 1 month, while the larger bomb would give fall-out over essentially the whole earth in about 10 years. For strontium 90 effects there is relatively little difference per unit fission yield since even the residence time in the stratosphere is small compared to the 28 year half-life of radioactive strontium and the 27 year half-life of radioactive cesium, which is produced at slightly higher yield than strontium 90, and which appears to be disseminated in about the same way.

The content of radiostrontium and radiocesium in the stratosphere is by direct measurement shown to be roughly the same though the radiocesium is somewhat higher possibly due to the slightly higher fission yield. The content of radiocesium in rainwater is comparable to that of strontium 90. Also, the content of radiocesium in the human body as measured by Marinelli at Argonne and Anderson and Langham at Los Alamos, agrees well with the fact that it has an average residence time in the human body of about 5 months as compared to many years for strontium 90. The radiocesium data are very interesting because of their bearing on the fall-out dissemination mechanism and the confidence with which we can establish the probable future behavior of radioactive strontium. The data confirm previous suggestions as to the dissemination mechanism, that is we find that radiocesium fall-out except of the local variety is carried down very largely in the form of moisture droplets and that there is some direct pick-up by leaves and grass on surfaces. It is captured and held tightly by the top two inches of most soils, so the water which falls and runs off in the form of rivers is clean by the time it has drained a short distance through soil. All of this is very similar to the radiostrontium behavior.

The plants pick the strontium 90, and radiocesium to a lesser extent, out of the soil and also off of their leaves and take it into their systems. There appears to be a discrimination mechanism which operates in most plants so that the strontium 90 content of the plant is considerably less relative to its calcium content than in the case of the soil. On the average, the discrimination factor between the top soil and plants against strontium relative to calcium seems to be about

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1.4. When the cows eat grass they further discriminate by about a factor of 7 in making milk so there is an overall protection factor for strontium 90 from the top soil to milk of about 1.4 x 7 or 10. Also, there is a further discrimination factor against strontium relative to calcium in the human body. This factor is not known too well, but is known definitely to be at least as large as 2 and is thought possibly to be as high as 8. Researches are now in progress to settle this. Therefore, there is a series of protective factors which makes the concentration of radiostrontium derived from milk relative to calcium in human bone not over 1/20 and possibly as little as 1/80 of that in the top soil. Of course, it should be pointed out that there is a considerable part of the fall-out which is picked up directly on the leaves and to this the factor of 1.4 does not apply, so for this fraction of the fall-out the protective factor may be reduced to 14. Since milk is the source of most of our calcium, this means that the actual ratio of radiostrontium concentration in new human bones relative to that in the top soil should approach these numbers.

It must be realized that though only a small part of the calcium is derived from vegetables and meat, a similar calculation must be made from this portion and the total average ratio obtained. It seems that the meat-vegetable overall discrimination factor is about 10; so, if 20 percent of the calcium is derived from such sources on the average, the average overall factor will be between 1/13 and 1/30. The experimental data on new human bone in children appear to give a smaller figure, 1/40, as mentioned later.

A matter of importance in connection with the amount of strontium 90 which one would expect to be deposited in human bone as a result of atomic weapon detonations is the calcium concentration in the top soil. Since calcium is so similar to strontium, it seems very likely, and the evidence confirms this, that high available calcium content of the soil will reduce the probability of strontium 90 being taken up into the plants. Of course this probably does not have nearly as great an effect on the uptake of the material which is picked up directly on the leaves. We might expect therefore that soils which are particularly low in calcium might show higher strontium 90 contents for the grasses grown on them. This is, in fact, so, and sheep and goats and cattle feeding on such pasture display a higher strontium 90 bone content.

How such calcium deficiencies in the soil should affect the strontium 90 uptake by the human population is a most important question. One sees immediately that food distribution systems are such that the food supply is derived from large areas, and that there is consequently a sharp reduction in the sensitivity of the human population to calcium deficiencies in local soils. This is brought out particularly well by the data on the radium contents of human bones and their obvious lack of strong dependence on the radium contents of local waters. But for people who consistently drink milk from cows grazing on such ground there should be a definite effect on the amount of radiostrontium uptake and the effect should be proportional to the radiostrontium content of the milk. So the question resolves itself largely into "What are the strontium 90 contents of the foods people in such regions actually consume?" We find on inspection of the food eating habits and calculation of the strontium 90 intake relative to calcium, that the increase in average strontium 90 concentration of the food due to the low calcium content of the particular soils can hardly be more than 5-fold for a soil calcium deficiency of 50-fold. That is, whereas normal soil carried about 20 grams of available calcium in the top 2.5 inches, a region with soil of only 0.4 gram per square foot would produce a human body burden equilibrium of about five times that which the normal soil would produce.

In order to understand the hazard of radiostrontium, which is generally agreed to be the most hazardous of the long-lived fission products, we try to establish the maximum permissible concentration both for occupational workers and for the population in general. These numbers have been set at 1 microcurie and 0.1 microcurie for the standard man, respectively. That is, an occupational worker may carry 1 microcurie of strontium 90 in his body, whereas the general public should not have over 0.1 of a microcurie of strontium 90 in the average standard adult. This last figure corresponds to a concentration of 100 micromicrocuries per gram of body calcium or what we call 100 Sunshine Units, that is, 1 micro-microcurie of strontium 90 per gram of body calcium is defined as 1 Sunshine Unit.

Now, we must try to see in some other way how our normal experiences can be brought to bear on the question: "How dangerous is atomic weapons testing from the point of view of radioactive fall-out?" At the present time we have in our bodies about 0.1 or 0.2 of a Sunshine Unit and children have about one-half of a Sunshine Unit. In a few minutes I will speak about the question of the variation from these average values, but assuming at the moment that these are the values, what is the threat or the hazard from these quantities? Obviously they are much smaller than the 100 Sunshine Unit tolerance figure mentioned above. To obtain a comparison with normal experience, let us consider the fact that we know in a general way the magnitude of the radiation levels to which we are normally subjected by the cosmic rays, potassium in our own bodies, and the uranium, thorium and potassium in the ground and in our surroundings. We know these quantities amount to something like 150 milliroentgens per year for an average person in this latitude. But we also know that there are considerable variations with conditions.

For example, a person living in a brick house may very well get 25 to 50 milliroentgens per year more than one living in a wooden house, because of the natural radioactivity of the bricks. It is also very well known that whereas at sea level in this latitude the cosmic ray dosage is 37 milliroentgens per year, at 5,000 feet altitude as in Denver, Colo., the dosage from cosmic rays is 60 milliroentgens per year, or a difference of 23 milliroentgens per year. What is this in terms of strontium 90 body burden?

First, we must consider what part of the natural radiation, if any, is similar to the radiation of strontium 90 in biological effect so we can say without doubt and hesitancy that the physiological effects, whatever they are, will be the same for the same energy absorbed. Fortunately, the cosmic rays seem to fit the bill. In other words, we are at liberty to compare the cosmic ray radiation dosages with the dosages from radiostrontium in our bone structure. The reason this is permissible is that the ionization density along the tracks of the mu-mesons which are the principal cosmic ray components at sea level and at altitudes of 5,000 feet are nearly the same as those of the yttrium 90 beta rays, the principal radiation which radiostrontium emits; that is, radiostrontium has a radioactive daughter, yttrium 90, which emits a very energetic beta ray and the ionization density along the track of this radiation is very similar to that of the mu-mesons of the cosmic rays and their disintegration electrons, and it is generally accepted by health physicists and radiobiologists that radiations of the same ionization density have very similar, if not identical biological effects for the same energy absorbed. The high energy of the yttrium 90 gives it an average distance of penetration in tissue of 2 millimeters so any effect of local non-uniformity of deposition of strontium 90 in the bone is removed. The cosmic ray exposure is, of course, uniform throughout the bone structure. Therefore, we can equate cosmic ray dosage with strontium 90 dosage and thus it is possible for us to say

that the difference between one altitude and another is equal in effect, other effects being equal, to a certain number of Sunshine Units in bone. Now to follow this thought through, 1 Sunshine Unit is equal to 3 milliroentgens per year. Therefore, the difference in annual cosmic ray radiation dosage between Washington, D. C., or any place at sea level in this latitude, and Denver, Colo. is equal to 8 Sunshine Units, that is, 16 times the present body burden of equilibrium bone or bone near equilibrium as we see it in young children who are growing now.

Therefore, we must examine whether anything in our experience indicates that these differences are significant in terms of the occurrence of the principal effects expected of radiostrontium, namely leukemia and bone cancer. Now of course when one looks for such vital statistics, one finds that they are very hard to acquire. However, the National Institutes of Health and the Department of Health, Education and Welfare, have given us statistics for the occurrence of leukemia and bone cancer for the year 1947 for the three cities, New Orleans, San Francisco, and Denver. They are shown in Table I.

TABLE I

Occurrence of Bone Cancer and Leukemia

(*New cases per year per 100,000 population*)

	Bone cancer	*Leukemia*
Denver	2. 4	6. 4
New Orleans	2. 8	6. 9
San Francisco	2. 9	10. 3

It is clear from this table there is no obvious effect of altitude, and it is also clear that there are other factors which are noticeably more important than cosmic ray dosage. Of course there may still be a considerable effect of altitude hidden in large fluctuations caused by other factors, which presumably are largely unknown and we cannot say that this *proves* anything. It does, however, give us some assurance from normal experience that the effect of eight Sunshine Units will not cause a detectable increase in bone cancer or leukemia.

This fits well with the laboratory data on animals and the limited experience on humans with radium. That is, 1 microcurie being 1,000 Sunshine Units, is still considered to be pretty safe on the basis of the laboratory data. It is set as a tolerance for occupational workers and it is therefore reasonable that eight Sunshine Units should give an effect so small as to be very, very difficult to detect. It is, I think, helpful for us, however, to realize that the present body burden of strontium 90 in new bone from the weapons tests that have occurred in the past is equal to the increase in cosmic ray intensity that goes with an increase of some 400 feet in altitude, a very small fraction of the difference in cosmic radiation intensity between Denver and sea level. Therefore, at the same time that we consider the possible effects of strontium 90 from such concentrations, we may deduce from our everyday ordinary experience limits on the effects to be expected. None of the evidence on the occurrence of bone cancer or leukemia as a function of altitude has given us any reason to believe that the present tolerance limits are in any way in error. The present body burdens in new bones are small compared to these limits.

Separate from the strontium 90 effects are the effects of general gamma radiation, the radiation that is received mainly from outside the human body, and which comes mainly from the very young fission products in the local fall-out area, but which can come in smallest part from radiocesium accumulating on the ground in the case of the stratospheric fall-out, or more importantly, from the shorter-lived

fission products deposited by the tropospheric fall-out. Of course, weapons tests are so conducted as to avoid exposures to local fall-out, so our present discussion of the effects of weapons will be restricted to the much smaller gamma ray doses from the offsite tropospheric and stratospheric types of fall-out. In time of war, of course, it would be the local fall-out which would be of more direct concern next to blast and thermal effects, and it is to this aspect of fall-out which FCDA addresses itself in the main. In regard to nuclear tests, we have to study the effects on human genetics and the possible effects of such doses of radiation on health. Let us again apply the criterion of normal human experience to this. Measurements have shown that the general average intensity of fall-out gamma rays from tests is 1 to 5 milliroentgens per year. Now the general magnitude of the effects to be expected from this can be compared with the natural radiation intensity. We find, as mentioned earlier, that such things as living in a brick house instead of a wooden house can amount to as much as 25 to 50 milliroentgens extra dosage per year, that there are certain areas in the world where the average dose in this country of 150 milliroentgens per year is exceeded by ten-fold, that people living on granitic rock as compared to those living on sedimentary rock receive about 70 milliroentgens per year more dosage due to the higher content of uranium and thorium in these rocks and that people living at higher altitudes have a higher natural cosmic ray dosage. Also, of course, we know that medical uses of X-rays can be considerably larger than any of these fall-out dosages.

We do have experience and valid evidence that the somatic effects other than cancer and leukemia, that is, the effects of radiation on ordinary human health, require dosages which are very much larger, of the order of 25 to 50 roentgen units in order to be observed as changes in the blood and 100 to 200 roentgens for injury symptoms; whereas the dosages we are speaking of from test fall-out are about one-hundred-thousand-fold smaller.

As for genetic effects, these are extremely difficult to evaluate, since there is so little known about human genetics. But judging from experience with plants, insects, animals, and lower organisms, there is every reason to expect some genetic effects of radiation. The question is how much radiation is required for a given level of effect. There are a certain number of mutations in every new human generation. Are these largely induced by natural radiation or are they mainly of chemical, or rather biochemical origin, or both? From a chemical point of view, it seems likely that not all the spontaneous mutations in the human or any other species are caused by radiation effects, because it seems likely that radiation acts in inducing mutations mainly via molecules which it generates in the human cell, and that the mutations are caused by these chemicals and therefore in a sense are chemical in nature. Now if this be so, and the radiation induced mutations are nearly always caused by chemicals which are produced in the first instance by radiation, then chemicals themselves which are not produced by radiation but have other origins, can cause mutations, so it seems likely that a major part of the natural or spontaneous mutations in any species is not radiation induced. This point is an important one to settle, for the reason that we have to compare the effects of fall-out radiation with the fraction of the natural spontaneous mutations which is due to the radiation we are normally subjected to. In other words, if the normal mutations are all due to radiation, then the effects of the additional radiation from general test fall-out, or from other sources of radiation such as atomic power, or the medical uses of isotopes and X-ray, will be larger. It seems likely, and many genetic authorities agree on genetic grounds with this conclusion, that a major portion of the spontaneous mutations of the human species is not due to radiation but due to other causes. Therefore,

fraction of the spontaneous mutations in the human species is taken as being due to irradiation. Now, what this fraction is, it is difficult to say, but Professor H. J. Muller has estimated that this might be 10 percent. Therefore, one estimates the 150 milliroentgens per year from natural radiation now causes about 10 percent of the spontaneous mutations, and therefore, that the test fall-out if continued indefinitely will, at the present level of about 1 to 5 milliroentgens per year, cause an increase in the natural spontaneous mutation rate of something like ½ of ten percent, or 0.2 of a percent of the spontaneous mutations. In the extreme, if it should prove that all of the spontaneous mutation rate is radiation induced despite the chemical arguments, the effect would be ten times as great, or two percent. Dr. Dunning of the Division of Biology and Medicine of the AEC estimated 1.4 percent in 1955 on similar assumptions (the Scientific Monthly p. 265—December 1955). This effect is one which is comparable to moving to a slightly different locality and is much less serious than changing from one house to another or doing any of a dozen things. The only important point is that genetic effects show only if large numbers of people are subjected to them. Therefore, we would expect that the effects of large populations changing their environment, such as living at a higher altitude, or living in a region of naturally higher radioactivity, should cause genetic effects, if test fall-out does so. An examination of vital records should be made to test for such effects and the Atomic Energy Commission is doing so as best it can. The United Nations Scientific Committee on the Effects of Atomic Radiation has been comparing the data on natural background dosages, and it is hoped that this study will be continued and that the search will be made for observable effects of variations in the natural background dosage, for it is certain that any effects due to gamma rays from fall-out must be already present in much larger measure due to the natural dosage.

II. Variation in Individual Strontium 90 Burdens

What is the likelihood that even though the average strontium 90 content be well within tolerance limits, that a few individuals should exceed tolerance limits? Let us consider first the case which will ultimately hold, the situation of complete equilibrium with the environment in so far as the strontium 90 burden is concerned. The only way we can make judgments about the expected individual variations from the mean concentration is by direct experiment on human body composition, not only for strontium 90 but for other analogous constitutents. Most of the recent data on the strontium 90 body burden are from odd bits of bone removed during surgical operations, but fortunately we have actual data for the strontium 90 content of the entire bodies of some several dozen stillborn children [1] in the city of Chicago in the year 1953. A strenuous effort is now being made on the Sunshine Project to continue this series and also to check the human bone data by analyses of complete skeletons. We present the distribution of the strontium 90 data for the stillborn children in Figure 1. Data for the occurrence of ordinary nonradioactive strontium in human bones have been published.[2] These obviously refer to the full steady state conditions and are obviously at least as nearly in equilibrium with the environment as the fall-out radioactive strontium ever will be. These data are presented in Figure 2. The occurrence of radium in the human body also has been used since it is chemically similar to both calcium and strontium, and therefore is a bone seeker and because it is obviously also in steady state equilibrium. The

[1] W. F. Libby, "Radioactive Strontium Fallout," Proc. Nat. Acad. Sci. 42, No. 6, 365–390 (1956); University of Chicago, Project Sunshine Bulletin No. 12, August 1, 1956.
[2] K. K. Tekian and J. L. Kulp, Science 124, 405 (1956).

data used were those by Palmer and Queen [3] in Figure 3. And, finally, we use the recent data on occurrence of normal potassium in human bodies as determined by Anderson and Langham [4] at the Los Alamos Scientific Laboratory as presented in Figure 4. All of these data show a normal frequency distribution as indicated by the theoretical curves. The respective widths of the curves (standard deviations) are 36 percent for radiostrontium, 40 percent for normal strontium, 40 percent for radium and 18 percent for natural radiopotassium. It is completely clear from these data that they agree with one another in general shape and that the magnitude of the distribution of the strontium 90 contents of the Chicago stillborn babies was not in any way anomalous. Therefore, we shall take the distribution curve for radiostrontium to be the same as for the normal strontium data. The occurrence of nonradioactive normal ordinary strontium in the bones should certainly tell us what the equilibrium distribution will be for radioactive strontium, and from it we should be able to learn the points about distribution which we cannot yet learn in any detail from the radioactive strontium itself. Turekian and Kulp noted in their study of normal strontium in human bone that in a given region the deviation from the average was about 34 percent of the average, that is, for human bone from the regions Colorado, Texas, Cologne, Bonn, Venezuela, Chile, Vancouver, China and India. In each instance the ratio of the standard deviation from the mean itself was taken and the average calculated to obtain 34 percent. Therefore, we take 34 percent as the expected standard deviation from the mean *for a given locality* for the eventual strontium 90 equilibrium burden in human bones.

With this result we can, assuming a normal error curve shape of the distribution of probabilities, answer the immediate question: What is the probability of an individual exceeding the tolerance even though the mean does not? On the basis of this analysis we find that at steady state and in equilibrium the variation from the mean will constitute an error curve with a shape corresponding to the standard deviation, being ⅓ of the mean. Therefore, at steady state among people living in a given locality, only one person in about 700 will have more than twice the average strontium 90 burden, and the chances of anyone having as much as three times the normal burden will be about one in twenty million.

Now what about the non-equilibrium distribution, when the strontium 90 is finding its way into the biological system? Obviously, the burden will be much lower here, but the deviation from the mean will probably be much higher percentagewise, particularly in adults where most of the bone has been deposited before strontium 90 was produced. The present strontium 90 content of adults depends very much on the growth rate and the metabolic activity of the various bones in the given individual's body which happens to be sampled. However, the specific concentration of the strontium 90 deposited will not exceed that in new bone developed entirely in the present biological environment, i. e., the local concentration in adult bone will not exceed that for the whole bone in young children, whose total bodies are composed of the mixture of strontium 90 and calcium which now is present in food. Since the present ratio for children to adults is about four to one for average total strontium 90 content, the factor of concentration in adults' active bone regions may be as much as four-fold greater than the whole body average. Thus the apparent spread for random bone samples taken from adults should be very large compared to the true equilibrium spread for these reasons. As equilibrium is approached, however, the spread must decrease very, very markedly.

[3] Hanford Report, HW-31242.

[4] E. C. Anderson, R. L. Schuch, W. R. Fisher, and W. Langham, "Potsassium and Cesium Radio[illegible] in People and Foodstuffs." (In press.)

The data on human bones indicate a very wide scatter, but it seems extremely likely that the variation is a reflection of the fact that the main skeleton of adult individuals is not in equilibrium with the present food supply, and that the variations reflect the different rates at which the various bones in the bodies of individuals are coming into equilibrium with the food supply in the general biological environment. A study of whole skeletons taken from one given locality which is now under way as a part of Project Sunshine will clarify the point about the variations among individuals in their rate of coming into equilibrium with the general biological environment. This study is under way in Dr. Kulp's laboratory.

It should appear from these studies that the variation from the mean of adults will be larger than the factor of one-third which apparently is normal for the type of equilibrium distribution considered above. It is, of course, very important to establish the truth of this prediction clearly. However, the general agreement in shape of the distribution curves for such widely different materials as normal potassium in whole bodies, radium, and normal elementary strontium in fragmentary human bone, and actual fall-out radioactive strontium in the whole bodies of stillborn children, give us good reason to believe that there is nothing extraordinary in the distribution of radiostrontium in human bone.

III. Variation of the Strontium 90 Body Burden With Locality

Most important of the causes of variation of the strontium 90 content of individuals with locality is, of course, the amount of fall-out in a given region. The general rules about the intensity of fall-out have been described above. For high-fired megaton weapons our present indication is that the fall-out is almost worldwide and for reasons of simplicity and in the absence of better information at the present time, we work on the model that this is a uniform distribution, over the entire world, of material that falls from the stratosphere. Further evidence and data on this point are rapidly being collected which will undoubtedly settle the stratospheric horizontal mixing question.

At the present time, the general latitudes in the Northern Hemisphere which lie between 10° and 60° North have the highest strontium 90 content. In the United States, which because of our proximity to the Nevada Test Site has unusually high fall-out, there are at the present time about 25 millicuries per square mile of strontium 90. For average soil this means a concentration in the top soil of about 50 Sunshine Units. With the factors of discrimination mentioned above, this means that an equilibrium body burden between 1.7 Sunshine Units and 3.9 Sunshine Units is to be expected. Actually, the present body burden in young children indicates that the lower value is probably more realistic. The present body burden in children—about 0.5 Sunshine Units—probably was derived from an average strontium 90 content in the top soil of something like 15 millicuries per square mile, or about 25 to 30 Sunshine Units during the time the strontium was being acquired. Thus we find that the experimental value for the ratio between the body burden of young children and the average concentration in the top soil is about 50 to 1; rather closer to the higher range of the laboratory results than to the lowest range.

Table II contains the latest data for the total strontium 90 fall-out as measured in United States soils, and Figure 5 displays these data graphically.

The Northern part of the United States has about 20 to 30 millicuries of strontium 90 per square mile, the Southern States are somewhat lower. The low value of 7 millicuries per square mile for Grand Junction, Colo., is probably due to local climatic and sample site conditions.

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TABLE II

Health and Safety Laboratory 1956 Survey of U. S. Soils for Strontium 90 Samples taken between October 8 and 13, 1956. Strontium extracted with 6N HCl at room temperature. Replicates represent individual soil aliquots taken after sampling and air drying. Each error term represents one standard deviation due to counting error

Sampling site	Depth	d/m/gm soil	mc/mi²	mc/mi² Average	Total
Albuquerque, N. Mex.	0–2″	0.078±0.001	7.5±0.1	7.3	
		0.075±0.001	7.2±0.1		
	2–10½″	0.008±0.002	4.4±0.9	3.4	
		0.005±0.002	2.4±0.8		
Atlanta, Ga.	0–2″	0.35 ±0.007	14 ±0.3	15	
		0.42 ±0.009	16 ±0.4		
	2–6″	0.018±0.004	2.8±0.6	3.0	
		0.021±0.003	3.3±0.5		
Binghamton, N. Y.	0–2″	0.32 ±0.007	17 ±0.4	18	
		0.35 ±0.007	18 ±0.4		
	2–6″	0.019±0.003	4.4±0.8	5.0	
		0.024±0.005	5.6±1.1		
Boise, Idaho	0–2″	0.23 ±0.006	20 ±0.6	22	
		0.26 ±0.006	23 ±0.6		
	2–6″	0.012±0.002	3.1±0.6	3.5	
		0.015±0.002	4.0±0.6		
Des Moines, Iowa	0–2″	0.31 ±0.007	23 ±0.5	23	
		0.31 ±0.007	23 ±0.5		
	2–6″	0.028±0.002	7.6±0.7	7.1	
		0.024±0.003	6.6±0.7		
Detroit, Mich.	0–2″	0.26 ±0.006	20 ±0.5	20	
		0.27 ±0.006	20 ±0.5		
	2–6″	0.038±0.003	7.3±0.5	7.8	
		0.044±0.003	8.4±0.6		
Grand Junction, Colo.	0–2″	0.10 ±0.001	7.8±0.1	7.0	
		0.091±0.001	7.1±0.1		
		0.11 ±0.019	8.2±1.4		
		0.070±0.013	5.1±1.0		
	2–10½″	≦0.002	≦0.45	≦0.48	
		≦0.002	≦0.51		
Jacksonville, Fla.	0–2″	0.11 ±0.009	7.3±0.6	7.3	
	2–6″	0.013±0.004	2.7±0.9	3.4	
		0.020±0.005	4.0±1.0		
Los Angeles, Calif.	0–2″	0.12 ±0.008	6.9±0.5	7.5	
		0.14 ±0.009	8.0±0.5		
	2–7″	0.009±0.002	3.3±0.9	2.8	
		0.006±0.002	2.2±0.7		
Memphis, Tenn.	0–2″	0.27 ±0.006	15 ±0.4	15	
		0.26 ±0.006	15 ±0.4		
	2–6″	0.028±0.003	6.5±0.7	6.6	
		0.029±0.003	6.6±0.7		
New Orleans, La.	0–2″	0.24 ±0.006	8.8±0.2	8.6	
		0.22 ±0.006	8.3±0.2		
	2–6″	0.009±0.002	3.3±0.9	2.8	
		0.006±0.002	2.2±0.7		
New York, N. Y.	0–2″	0.21 ±0.006	10 ±0.3	12	
		0.29 ±0.007	14 ±0.3		
	2–6″	0.072±0.004	14 ±0.8	14	
		0.068±0.004	14 ±0.8		
Philadelphia, Pa.	0–2″	0.17 ±0.005	12 ±0.4	12	
		0.16 ±0.005	11 ±0.4		
	2–6″	0.029±0.003	7.3±0.8	6.8	
		0.026±0.003	6.4±0.7		
Rapid City, S. Dak.	0–2″	0.29 ±0.006	20 ±0.4	22	
		0.34 ±0.006	23 ±0.4		
	2–6″	0.053±0.004	12 ±1.0	11	
		0.045±0.003	10 ±0.7		
Rochester, N. Y.	0–2″	0.22 ±0.006	16 ±0.4	16	
	2–6″	0.013±0.002	2.5±0.4	2.5	
		0.013±0.002	2.5±0.4		
Salt Lake City, Utah	0–2″	0.32 ±0.007	22 ±0.5	22	
		0.33 ±0.007	23 ±0.5		
		0.31 ±0.007	22 ±0.5		
	2–8″	0.016±0.002	5.7±0.7	5.8	
		0.016±0.002	5.9±0.8		
Seattle, Wash.	0–2″	0.46 ±0.011	17 ±0.4	17	
		0.44 ±0.010	16 ±0.4		
	2–6″	0.051±0.007	9.4±1.2	9.5	
		0.052±0.004	9.6±0.7		

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The differential rates at which the fall-out has been occurring probably are best measured by the so-called "pot collection" method. A bucket with vertical walls of appreciable height is placed out in the open and allowed to collect the total fall-out for a given period including the rain, snow, dust, etc. The bucket is left out whether it has rained or not and covers the total fall-out for a given period. Figures 6 and 7 give the curves so obtained for New York and Pittsburgh areas together with the estimated errors of measurement. It is interesting to note the changes in slope and to correlate them with the occurrence of test activities and the relatively short-lived tropospheric fall-out. The minimum slopes which appear during quiet periods when no one is testing are the stratospheric fall-out of which we have spoken and these slopes when we have enough pots operating all over the world will, when taken together with the results of the measurements of the amounts of radiostrontium and radiocesium in the stratosphere, give an accurate value for the stratospheric residence time and settle the question.

In addition to the intensity of fall-out, the question of the fraction of the radiostrontium, and, for tropospheric fall-out, the radioiodine of eight-day half-life that is in assimilable form is an important one. So far most fall-out strontium appears to be completely water soluble and therefore most assimilable, though continued tests on this point should be made. Direct leaf pick-up of course promotes assimilation of the strontium because the plant differentiation against strontium when it assimilates it from soil thus is avoided. Another factor is, of course, the concentration of available calcium in the soil. By available calcium we mean calcium which is available to plants and not the total calcium in the soil. It is known that soils which are high in available calcium produce plants of lower radioactive strontium content; that is, the radioactive strontium to calcium ratio in the plant is lower as a direct consequence of the lower concentration of radiostrontium in the available soil calcium. In addition, as mentioned previously, plants tend to prefer calcium to strontium with a discrimination factor of about 1.4. Sheep which grow in certain areas of Wales have shown concentrations in their bones approaching 150 Sunshine Units, while sheep and cattle growing in the U. S. have hardly ever exceeded one-fifth of this. The Welsh soil in certain areas is very low in calcium and as a result grows grasses of high radiostrontium content. Of course, it is clear that fertilization with calcium will immediately relieve this difficulty, but in the absence of such fertilization, the question is: How serious is the effect of calcium deficiency in producing strontium 90 pick-up through the food chain?

As was remarked earlier, there is an averaging which occurs in food distribution systems and calcium deficient soils are naturally rather poor producers and as a consequence the weight of the food so produced is less than for a good well fertilized, well balanced soil. This factor reduces the flow into the general food stream of material of exceptionally high strontium 90 content. It therefore will probably be sufficient to consider the radiostrontium of milk, since milk is the main source of calcium, in order to test for the radiostrontium content of the diet in given areas. Direct measurements have shown that a factor of five encompasses the total variation due to all factors including calcium deficiencies in soils.

The general intake must depend on the food distribution pattern and the relatively small fluctuation in milk contents must reflect this. The number of individuals who rely totally on the food output of soil of very low calcium content is very small indeed, but it must be true that these individuals if they grew up on a provincial, isolated farm would have as much as ten to 50 times the normal

average strontium 90 content. The normal calcium concentration in soils in the United States is about 20 grams per square foot for the top 2.5 inches and about the poorest soil known has about 0.4 gram available calcium per square foot for the top 2.5 inches—a deficiency factor of 50.

It is clear from a detailed examination made by the author for people living in calcium deficient areas with normal food distribution patterns, that a factor of 5 is about as large an effect as can be expected from a fifty-fold deficiency of calcium in the soil. The food from outside of the calcium deficient area reduces by a factor of about ten the increase in strontium 90 pick-up rate which would be expected from the calcium deficiency in the soil if people lived entirely off the soil for their whole growing period of 20 years or so.

The food of lowest strontium 90 content is fish flesh, because of the great dilution the fall-out receives by the hundred meters of sea water above the thermocline, which rapidly mix with the fall-out within a few hours or days. This means that the specific concentration of radioactive strontium, or any other fall-out constituent in sea water, is relatively very much lower than it would be in soil. For example, 100 meters of sea water has 370 grams of dissolved calcium per square foot as compared to the average of 20 grams per square foot for the top 2.5 inches of soil which absorbs and holds the fall-out radiostrontium. Therefore, in principle sea food and fish are lowest among foods in content of radiostrontium fall-out.

IV. Effects of Continued Testing and General Conclusions

In summary, then, we see that the present body burden of strontium 90 from atomic weapons tests in the United States corresponds to the radiation dosage to the bones which would result from a few hundred feet increase in altitude and the present vital statistics show no observable effect on the occurrence of bone cancer or leukemia of much larger changes in altitude. The tolerance figure of 100 Sunshine Units, or 0.1 of a microcurie for an average individual or 100 micromicrocuries per gram of body calcium, that is recommended now is about two hundred times the present level for new bone in the U. S., and it will not be exceeded by fall-out from weapons tests in any foreseeable circumstances.

The distribution of strontium 90 burdens among individuals *for a given locality* will be a normal error curve with a standard deviation of about one-third of the average concentration. This means that about one individual in 300 will have more than twice the normal average value for a given locality, and that about 1 in several million will have three times the average value.

The effect of locality is more important, however, particularly in the effect of calcium deficiency in the soils. Careful consideration of this question indicates that there will be very few individuals who show a strontium 90 content which is strictly inversely proportional to the available calcium concentration of the soil in their region. This is due to the fact that food distribution systems automatically average over a wide area and people assimilate their calcium slowly. Most people drink milk and eat cheese and other calcium-bearing foods from a rather wide area, and this effect reduces by an estimated factor of ten the potential effect of calcium deficiency in the local soils.

On the basis of laboratory experiments the human body concentration of strontium 90 at equilibrium will be between 13 and 30 times less than that in top soil. The present data indicate that the higher figure is closer to the truth and so we will be conservative in taking the figure of 20 for this ratio. Therefore

the present burden of 50 Sunshine Units in the top soil of the United States may eventually lead to as much as 2.5 Sunshine Units in the human bones, but more likely will lead to about 1.7.

Of course, as testing continues and more fall-out occurs, the levels will rise. In the United States the strontium 90 that still resides in the stratosphere at the present will fall out according to our expectations at a rate which just about compensates for the decay of the material already deposited, so that no great additional increase from this source is to be expected from weapons fired in the past. If the testing should continue at about the same rate as it has averaged over the last 5 years, then we should at equilibrium, after an infinite time, approach a level of 8 times the present rate, since the average life of strontium 90 is 40 years. This assumes that the future testing will be conducted so as to give in each future 5-year period the same as the last 5 have. And so we would expect in the United States at that time an average human strontium 90 concentration of 20 Sunshine Units with the conservative factor of 20 between the top soil concentration and the concentration in human bone, or 5 Sunshine Units if the factor of 80 is used. In other words, in the United States something between 5 and 20 Sunshine Units would be the equilibrium concentration of human bones if testing continued indefinitely at the average rate of the past 5 years. This level would be approached only after a few decades. After 28 years the level would be half of this equilibrium value, and after another 28 years, 56 years total, from an arbitrary beginning which we have set as 1952, we would expect in the year 2008 three-fourths of the equilibrium figures. So somewhere between 4 and 15 Sunshine Units of strontium 90 in human bones in the United States might result from the present type of testing being continued for the next 50 years.

In those certain areas in the world where the soil is low in calcium, this level might go five-fold higher. At the present rate of testing we might indeed approach the figure of 100 Sunshine Units, the tolerance limit for large populations, at the beginning of the 21st century for these certain limited regions in the world. The observed conditions in these regions could be relieved, however, by fertilization of the soil with calcium, either calcium nitrate or lime being used, as appropriate from other considerations.

The Sunshine Project continues to study the problems of worldwide fall-out—the stratospheric inventory of radiostrontium and radiocesium, the occurrence of these isotopes in the soils and water and the biosphere all over the earth, the biological effects at certain levels of contamination with strontium 90, and to a lesser degree with cesium 137, and the possible genetic effects of the low gamma ray dosages associated with worldwide fall-out from atomic tests. All of these are studied not only with the point in mind of devising methods of protection against atomic warfare, but also with the thought of possible application in the remote event of industrial accidents which may happen in connection with certain of the peaceful uses of atomic energy, particularly atomic power. Certainly an understanding of the basic principles of worldwide fall-out is applicable to the control and safe-handling of isotopes. All of this is done in collaboration with the United Nations Scientific Committee on the Effects of Atomic Radiation, and it is to be hoped that as the data appear all of the countries in the world will join together in this international effort to understand better the effects of the great new fact in life, the nuclear atom.

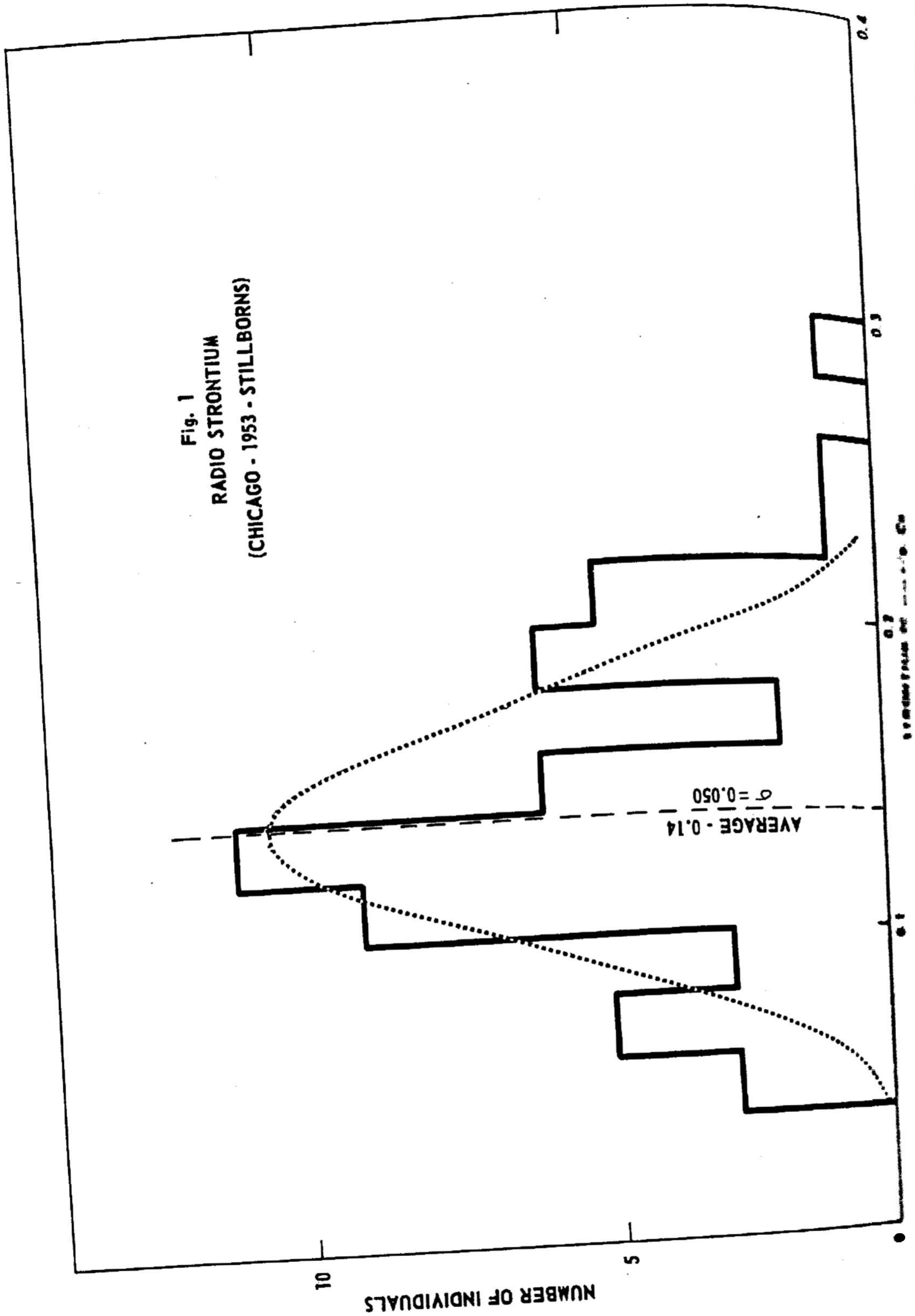

Fig. 1
RADIO STRONTIUM
(CHICAGO - 1953 - STILLBORNS)

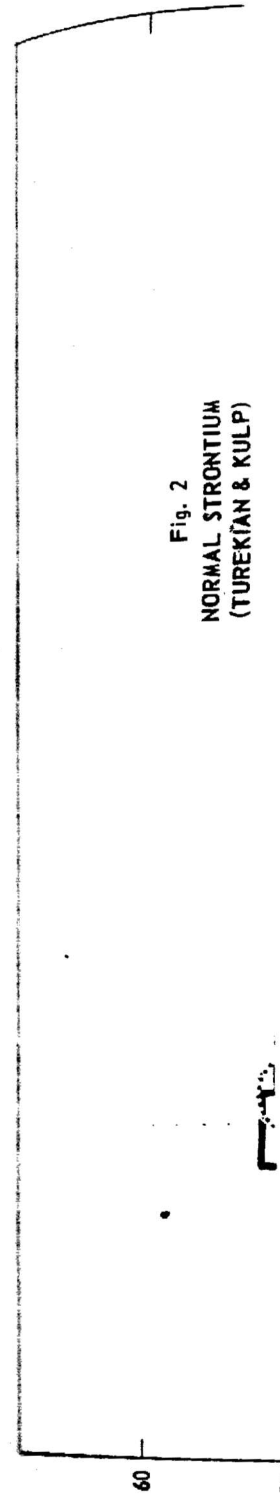

Fig. 2
NORMAL STRONTIUM
(TUREKIAN & KULP)

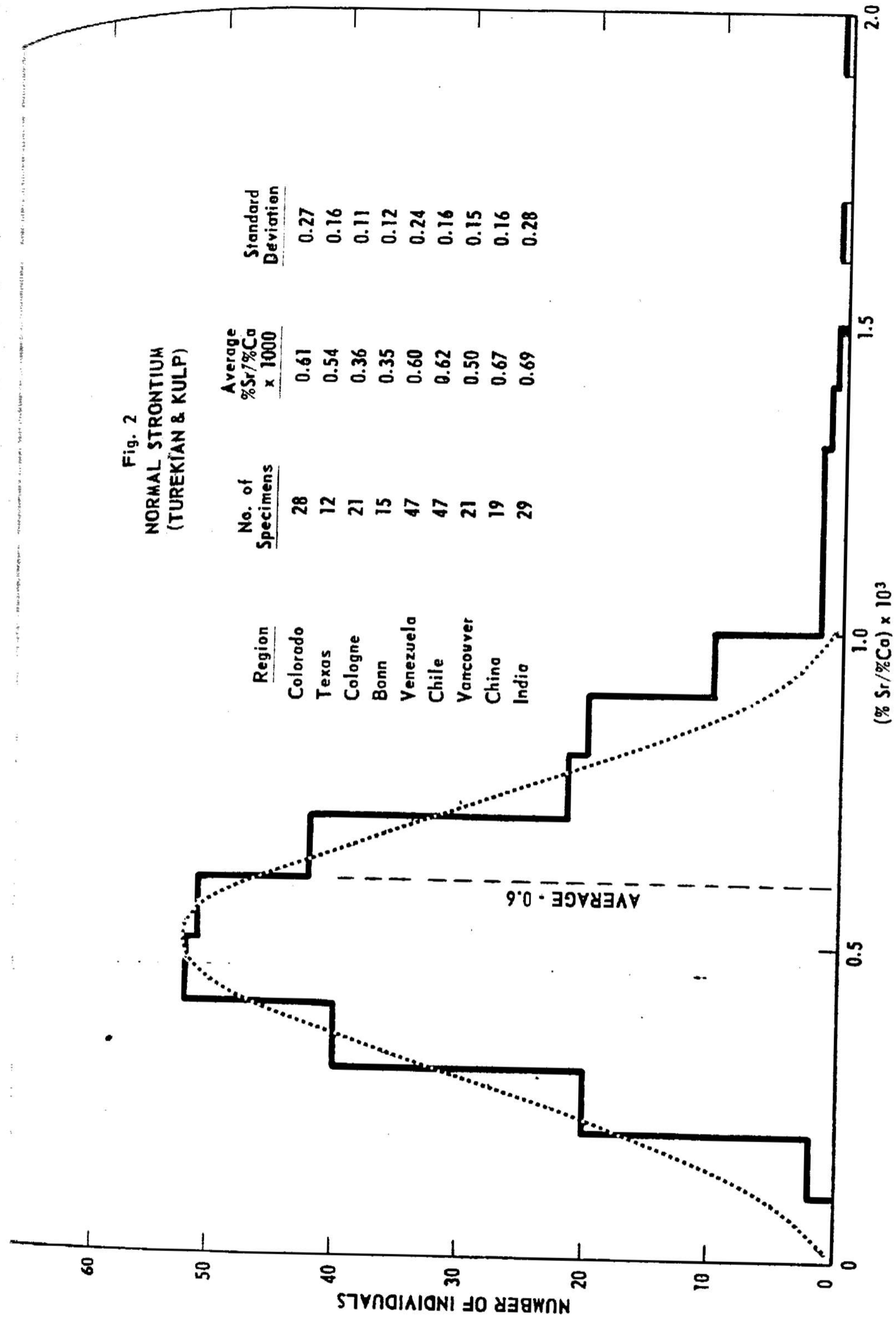

Fig. 2
NORMAL STRONTIUM
(TUREKIAN & KULP)

Region	No. of Specimens	Average %Sr/%Ca x 1000	Standard Deviation
Colorado	28	0.61	0.27
Texas	12	0.54	0.16
Cologne	21	0.36	0.11
Bonn	15	0.35	0.12
Venezuela	47	0.60	0.24
Chile	47	0.62	0.16
Vancouver	21	0.50	0.15
China	19	0.67	0.16
India	29	0.69	0.28

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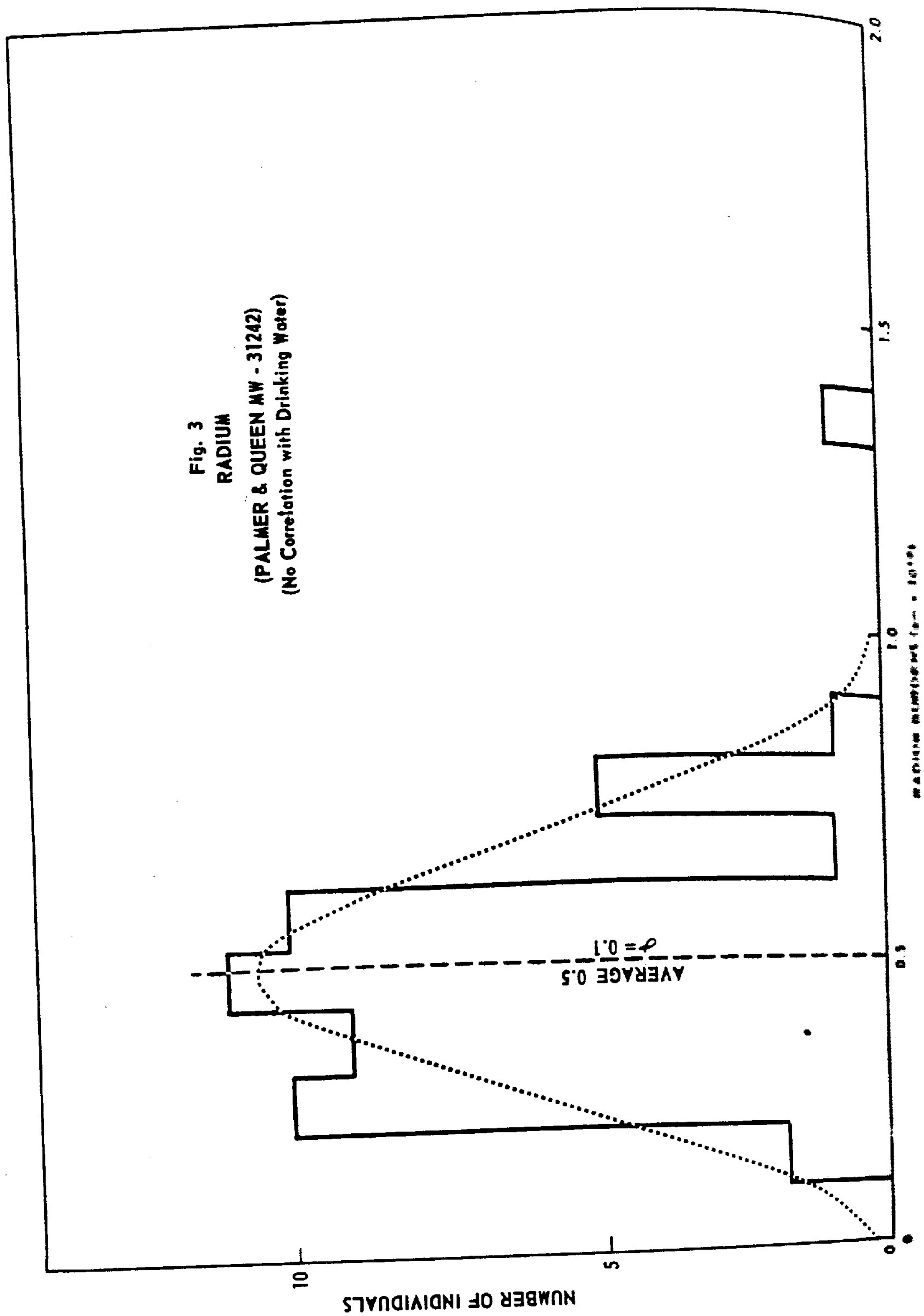


Fig. 3
RADIUM
(PALMER & QUEEN MW - 31242)
(No Correlation with Drinking Water)

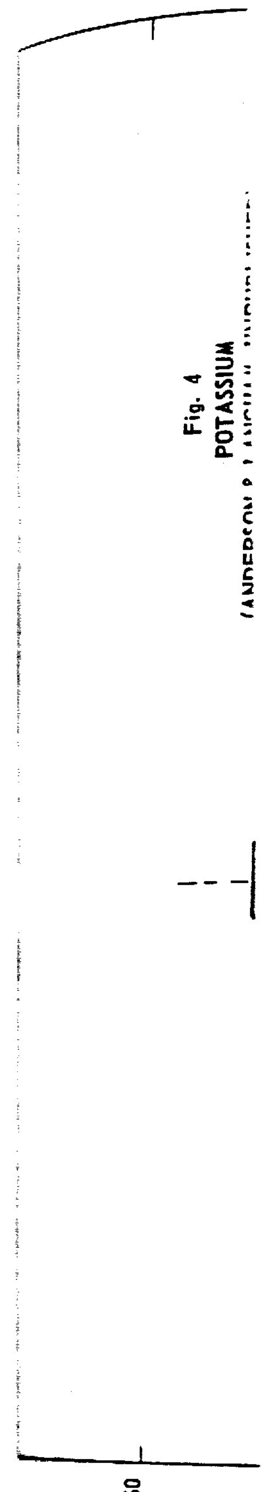


Fig. 4
POTASSIUM

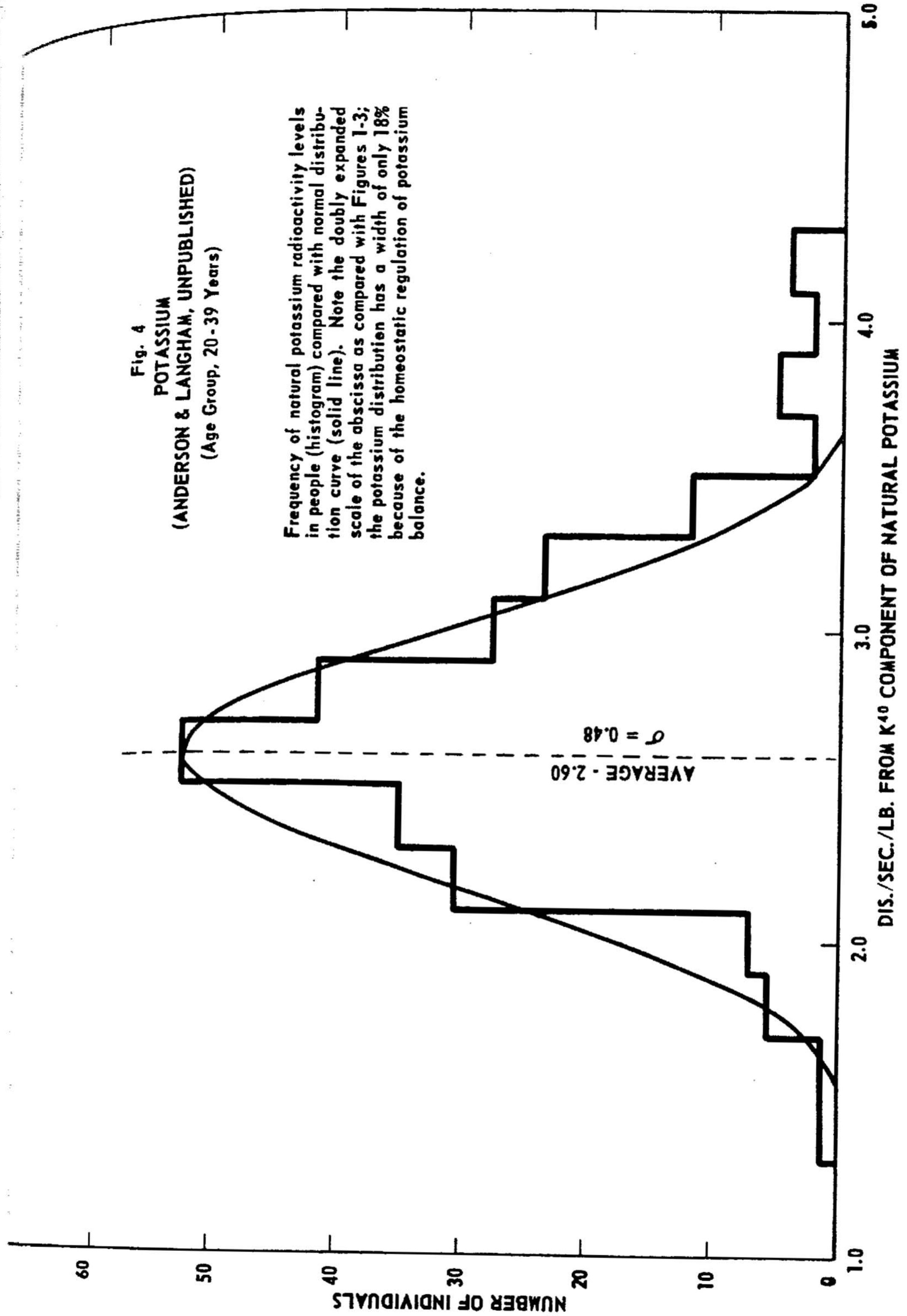


Fig. 4
POTASSIUM
(ANDERSON & LANGHAM, UNPUBLISHED)
(Age Group, 20-39 Years)

Frequency of natural potassium radioactivity levels in people (histogram) compared with normal distribution curve (solid line). Note the doubly expanded scale of the abscissa as compared with Figures 1-3; the potassium distribution has a width of only 18% because of the homeostatic regulation of potassium balance.

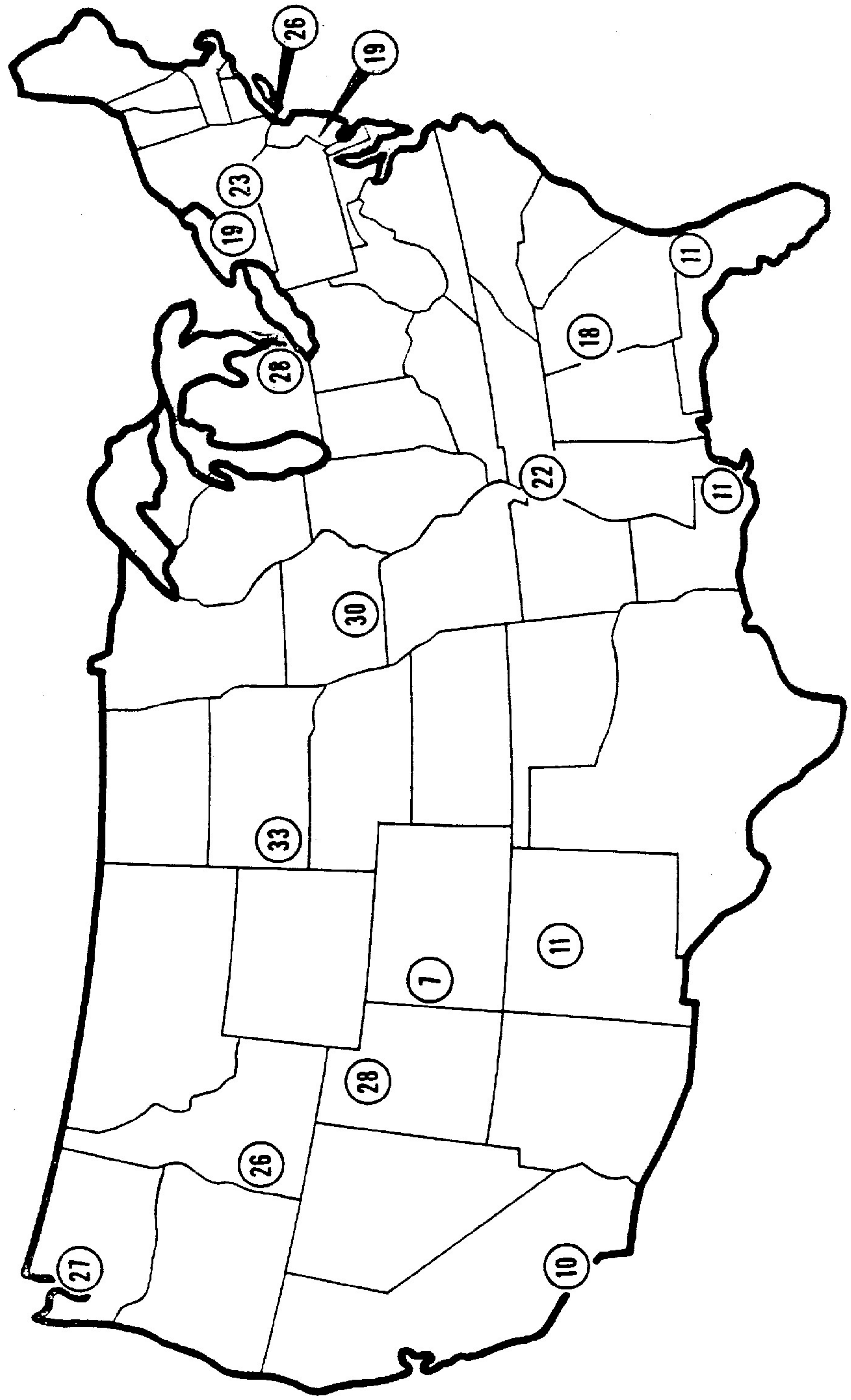
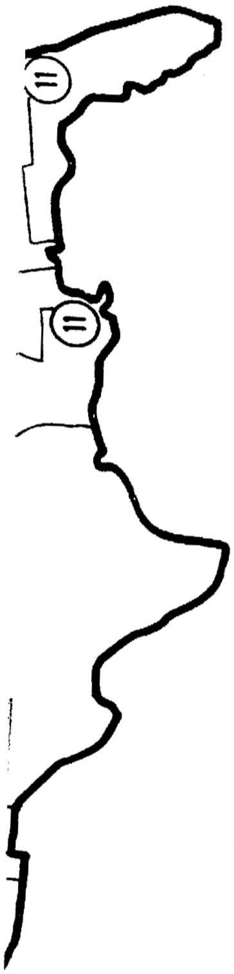


Fig. 5

Sr^{90} IN U. S. SOIL (HASL - OCT. 8, 1956) (HCl EXTRACTION METHOD)



Numbers are in mc/mi² at individual site.

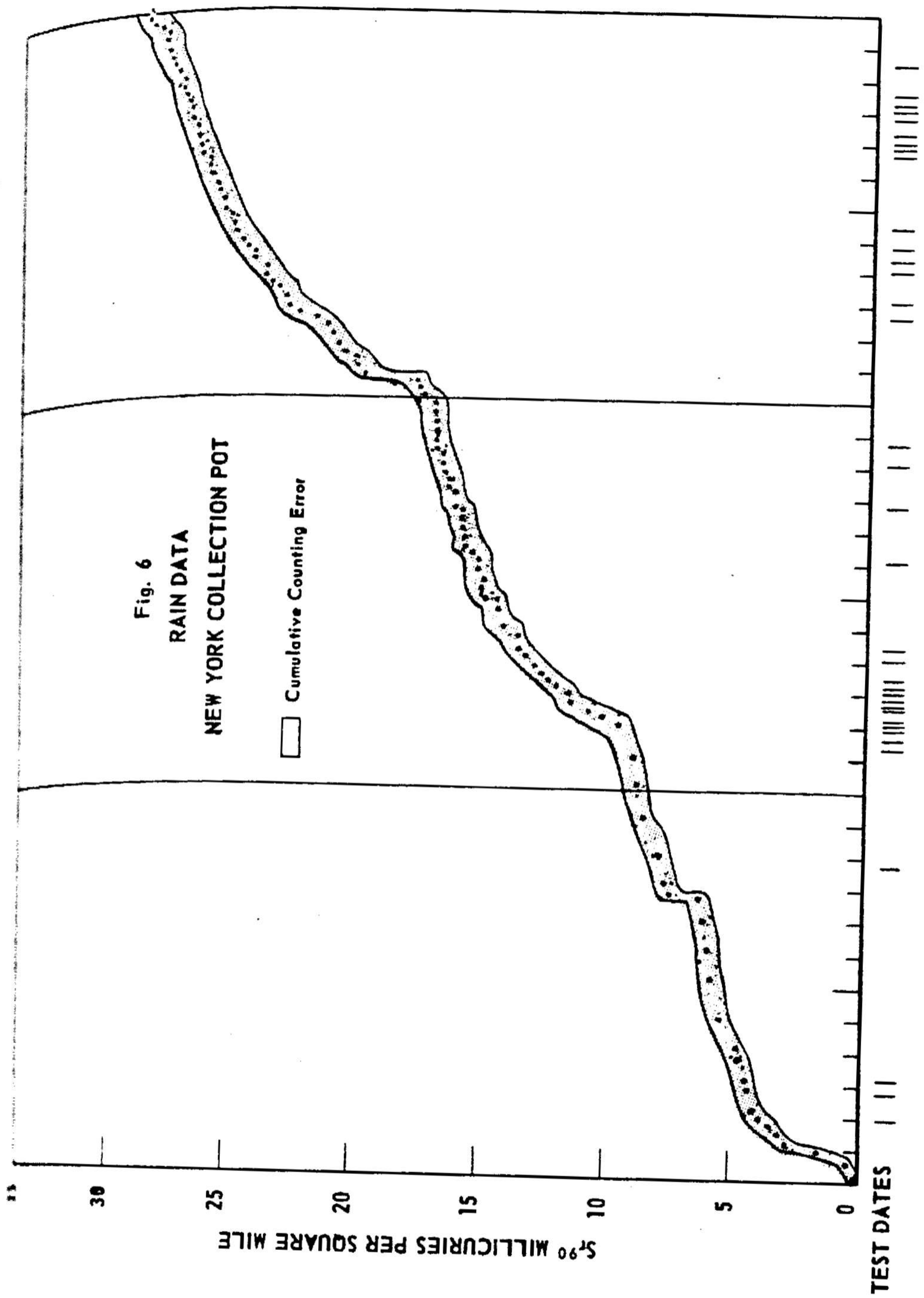


Fig. 6
RAIN DATA
NEW YORK COLLECTION POT

5004228

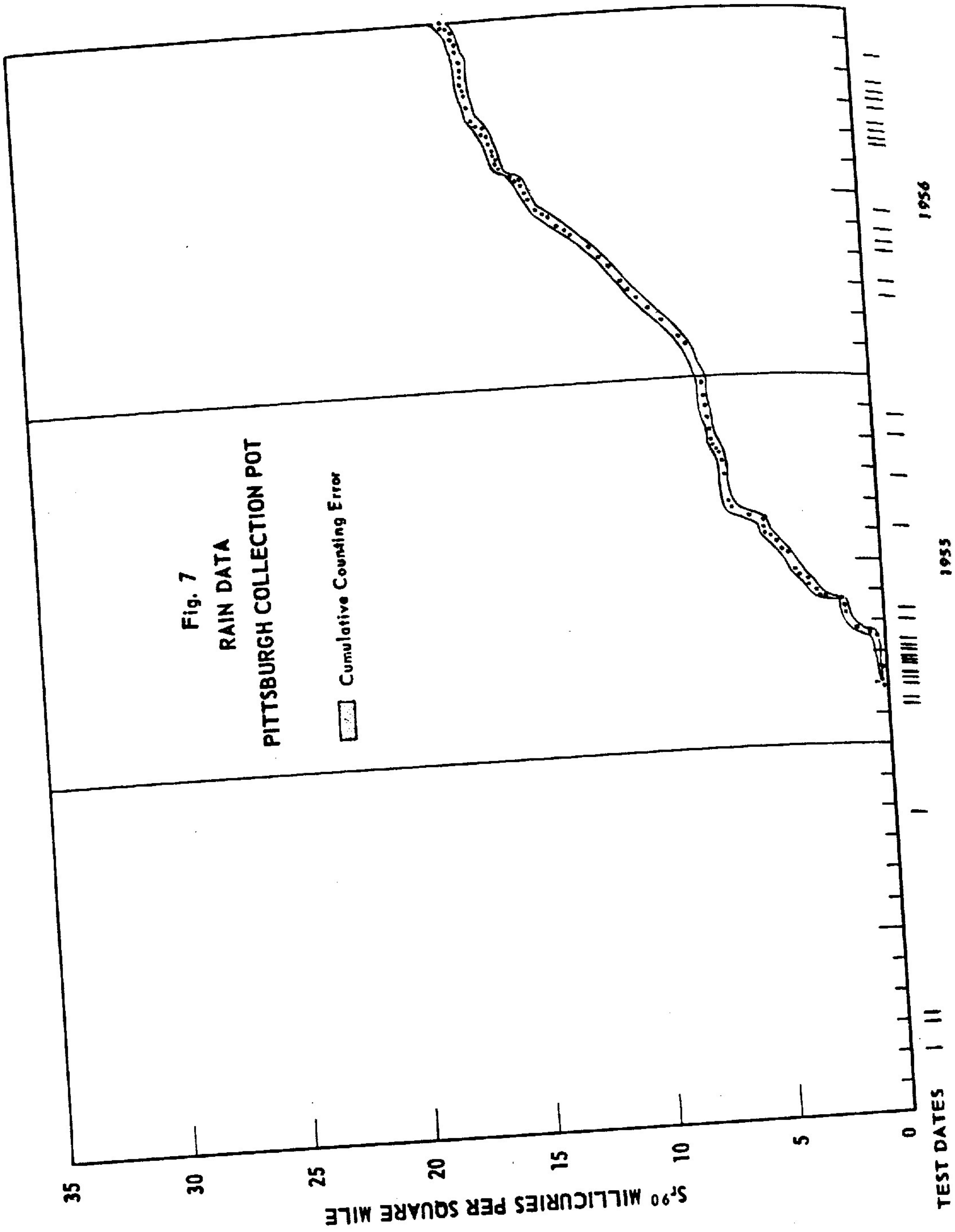


Fig. 7
RAIN DATA
PITTSBURGH COLLECTION POT